

UNIVERSITE DE GENEVE
Département de physique
nucléaire et corpusculaire

FACULTE DES SCIENCES
Professeur R. Mermod

CARACTERISTIQUES DE LA PRODUCTION DE K^0 DANS LES INTERACTIONS
 K^+p DE 8,2 GeV/c ET DANS LES INTERACTIONS K^-p DE 10,1 GeV/c

(CHARACTERISTICS OF K^0 PRODUCTION IN K^+p INTERACTIONS
AT 8.2 GeV/c AND K^-p INTERACTIONS AT 10.1 GeV/c)

THESE

PRESENTÉE A LA FACULTE DES SCIENCES
DE L'UNIVERSITE DE GENEVE
POUR OBTENIR LE GRADE DE DOCTEUR ES SCIENCES PHYSIQUES
PAR

Ryszard STROYNOWSKI
de Pologne

THESE No. 1612

CERN - GENEVE

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La faculté des sciences, sur le préavis du professeur Ronald MERMOD, directeur de thèse, et d'une commission composée du professeur Henri RUEGG et du docteur M.R.O. MORRISON (C.E.R.N.).

autorise l'impression de la présente thèse, sans exprimer d'opinion sur les propositions qui y sont énoncées.

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Pour Le Doyen:

E. L. Ruch

Thèse

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Vice-Doyen

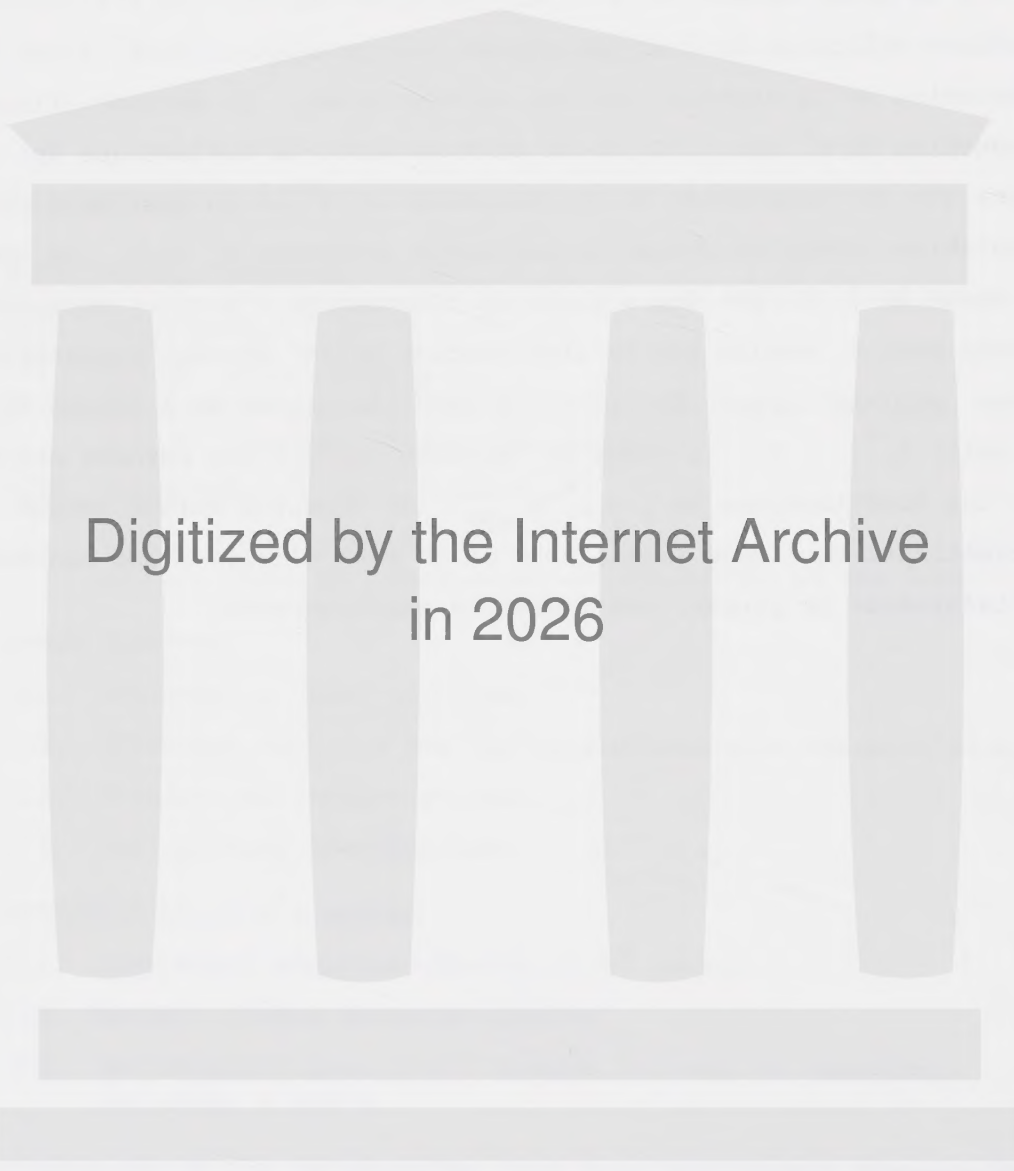
CHARACTERISTICS OF K_S^0 PRODUCTION IN K^+p INTERACTIONS

AT 8.2 GeV/c AND K^-p INTERACTIONS AT 10.1 GeV/c

1.	INTRODUCTION	1
2.	EXPERIMENTAL PROCEDURE	7
2.1.	Experiment K^-p at 10.1 GeV/c	7
2.1.1.	Film exposure	7
2.1.2.	Scanning measuring and processing of the data	9
2.1.3.	Hypothesis and decay weights	11
2.2.	Experiment K^+p at 8.2 GeV/c	13
2.2.1.	Film exposures	13
2.2.2.	Scanning, measuring and processing of the data	14
3.	CROSS SECTIONS	22
3.1.	Topological cross sections	22
3.2.	The cross sections for the various reaction channels with K^0	24
3.3.	Statistical isospin weights	27
3.4.	Multiplicity distributions	28
4.	DISTRIBUTION OF K^0 - MESONS	37
4.1.	Laboratory momentum spectra of K^0 - mesons	37
4.2.	Center of mass momentum spectra	38
4.3.	The distributions of K^0 - mesons in terms of invariant variables t and M	41
5.	COMPARISON OF THE EXPERIMENTAL DATA WITH PHASE-SPACE PREDICTIONS	60
6.	PARAMETRISATION OF THE DIFFERENTIAL CROSS SECTION	73
7.	CONCLUSIONS	83
8.	ACKNOWLEDGEMENTS	85

SOMMAIRE

Une étude des réactions avec échange de charge $K^+p \rightarrow K^0 X^{++}$ à 8.2 GeV/c et $K^-p \rightarrow \bar{K}^0 X^0$ à 10.1 GeV/c est présentée dans cette thèse (X désigne le système de toutes les particules secondaires différentes du K^0 , la masse effective de X sera désignée par M). On y trouvera les sections efficaces de tous les canaux avec production de K^0 ainsi qu'une discussion de la distribution des multiplicités. La section efficace de production du K^0 est $\sim 40\%$ de la section efficace inélastique Kp. On verra que les propriétés de la production du K^0 et du système X sont semblables lorsqu'on change la particule incidente K^+ en K^- . Le spectre de masse de X ($d\sigma/dM$) des régions de résonnances s'accroît exponentiellement avec M, tandis que la distribution $d\sigma/dt'$ décroît exponentiellement comme $\exp(-At')$ pour $0 < t' < 1.0 \text{ GeV}^2$, la valeur de A dépend de la masse M selon $M^{-\alpha}$ ($\alpha \approx 2$). L'effet de "scaling" prédit par Feynman est discuté sur les distributions de $X = p_L^*/p_{LMAX}^*$. On démontre qu'une simple paramétrisation à deux variables M et t' peut décrire d'une manière satisfaisante la plupart des résultats expérimentaux.



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1. INTRODUCTION

In the history of the high energy elementary particle physics one may distinguish two different research approaches. One is to study the general behaviour of the particle collisions, the second is to study a particular sample of events which come from a very specific reaction mechanism. For many years the distinction between these two approaches was defined by the experimental technique used. In the early years of particle physics the general behaviour of the collisions was studied using cosmic rays as the particle source and counters and nuclear emulsion as the detectors. However, the amount of information which one can extract by this method is rather limited because of many experimental difficulties e.g. determination of the momenta of the incoming and secondary particles or their charge in nuclear emulsion or precision of measurements with counters. The much more precise bubble chamber and counter experiments performed at big accelerators dealt mainly with few definite reaction channels with relatively small number of particles in the final state. Those experiments concentrated mainly on the study of resonance production and quasi-two-body processes which represent only a small fraction of the total cross-section. Even with the present, highly developed techniques, counter experiments have difficulties in measuring events with high multiplicity. In bubble chamber experiments, at present accelerator energies, about 60% of the events measured and processed cannot be identified because of production of two or more neutral particles. This percentage will probably increase with increasing energy and average multiplicity. One may ask therefore the question, whether there are some very general simple features of hadron collisions, which we are missing when studying specific reaction channels separately. This question leads to the idea of the study of "inclusive" reactions i.e. study of the sum of all possible reaction channels with a given particle in the final state

$$A + B \rightarrow C + \text{anything}$$

(1.1.)

From the enormous amount of data accumulated during the past 20 years of high energy hadron physics one may select the following general features [1] as the most important.

1. The total cross-sections for the collisions of hadrons seem to be constant at high energy.
2. The low multiplicity final states are dominated by resonance production and in particular by quasi-two-body channels. The cross-sections for these, however, decrease as p_{LAB}^{-n} [2], with the exception of diffractive processes for which the cross-section is energy independent, $n \approx 0$.
3. The transverse momentum of secondary particles is much smaller than allowed by phase-space, the average value being 300-400 MeV/c. It depends very weakly on energy and on the kind and multiplicity in the final state of particle studied.
4. There exist "leading" particles i.e. the two incoming particles tend to preserve their direction and momentum.
5. The multiplicity of the final state changes slowly with energy, again much slower than allowed by phase-space.

These features, together with the results from deep inelastic electron-proton scattering experiment [3] indicating that the distributions for the hadrons produced in ep collisions are energy independent at higher energies, have provided the basis for two rather general models of high energy hadron collisions, which gave definite experimental predictions. These were the hypotheses of limiting fragmentation and of scaling.

The hypothesis of limiting fragmentation introduced by Benecke, Chou, Yang and Yen [4] asserts, that when two hadrons collide, each of them separately breaks into fragments, and that fragments of the target approach, as the energy increases, a limiting distribution in the laboratory frame, while the fragments of the projectile approach a limiting distribution in the projectile rest frame.

In other words the distribution of the fragments of one of the colliding hadrons does not depend on the other. In the deep-inelastic electron-nucleon collisions the situation is simpler since only the nucleon breaks up and we have fragments of only one particle in the final state. This hypothesis gives definite predictions for the experimentally measurable distributions namely that for the reactions of the type (1.1.) the distribution $1/\sigma_{TOT} \cdot d\sigma/dp_{LAB}$ for particle C should become energy independent at high energy, and also it should become independent of the projectile particle. The hypothesis as presented in ref. [4] does not specify how fast the limit should be approached, suggesting however, that in general this will occur slowly. Chan, Hsu, Quigg and Wang [5] have suggested that the limiting distribution for the reaction (1.1) should be obtained already at present accelerators energies i.e. below 30 GeV, when the system (ABC) has exotic quantum numbers, otherwise the limit should be approached as $s^{1/2}$. The hypothesis of limiting fragmentation and the suggestion from ref. [5] have found already confirmation in several experiments [6] but contradictions are also reported [7].

The second hypothesis is that of scaling proposed by Feynman [8]. This refers to the inclusive reactions of the type (1.1) for which "anything" contains all possible final states and also the whole spectrum of the particle C multiplicities. Therefore at present energies only reactions of the type

$$A + B \rightarrow \pi + \text{anything}$$

fulfil the requirements of Feynman's scaling hypothesis. Other particles such as protons or kaons are at present accelerators energies not often produced with multiplicity greater than 1, so only at higher energies, when the cross-section for the $p\bar{p}$, $K\bar{K}$ or $\Lambda\bar{\Lambda}$ pair production will be big enough, the scaling hypothesis may be tested. The scaling hypothesis asserts, that while in principle the single particle invariant distribution is a function of three variables e.g. $f(p_{||}^*, p_{\perp}, s)$; centre of mass longitudinal

and transverse momentum and the energy squared, for the developed inclusive reactions it scales, i.e. becomes a function of only two variables $f(x, p_{\perp})$, where x is the normalised longitudinal momentum

$$x = \frac{2p_{\parallel}^*}{\sqrt{s}} \sim \frac{p_{\parallel}^*}{p_{\max}^*}.$$

In other words it asserts, that the experimental center of mass distributions $E^* \frac{d\sigma}{dx}$ should become energy independent for inclusive reactions at asymptotic energies.

In the high energy limit the hypothesis of limiting fragmentation is equivalent to the scaling hypothesis in the regions of $x \approx \pm 1.0$. However, scaling is more general since it gives also predictions for the central region of the x distributions ($x \approx 0$), which may correspond to some other reaction mechanism e.g. pionisation.

The experimental evidence presented at the International Conference on Elementary Particles in Amsterdam (1971) give support for the hypothesis of scaling, however, the important test in the region of $x \approx 0$ is not yet performed. The ideas described above had great impact among both theorists and experimentalists, and the study of inclusive reactions of all kinds became an important part of high energy hadron physics.

In this work we have studied the reactions

$$K^+ p \rightarrow K^0 + \text{anything at } 8.2 \text{ GeV/c}$$

$$\text{and } K^- p \rightarrow \bar{K}^0 + \text{anything at } 10.1 \text{ GeV/c}.$$

The great advantage when studying these reactions with the bubble chamber technique, is that the K^0 (or $\bar{K}^0$) is observed to decay inside the bubble chamber allowing for fairly precise measurement and identification of the event thus in general avoiding any experimental ambiguities. The results presented in the following sections are not the results of the work of only one person. The effort of many people in seven collaborating laboratories provided the measurements, identification and processing of the events during the past seven years (see section 2). The experiments are not yet completed, but

the results presented are based on fully analysed and hence unbiased subsamples of the data. The most important results are already published in the article by J.V. Beaupre et al., Nuclear Physics B30 (1971) 381.

In section 2 the experimental procedure for obtaining and processing of the data is described. Section 3 describes the determination of the cross-sections and sections 4, 5 and 6 give the general characteristics of the K^0 -mesons produced in both experiments, the comparison with phase-space predictions and an attempt to parametrise the experimental distributions. In section 7 the main results of the analysis are summarized.

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2. EXPERIMENTAL PROCEDURE

2.1 Experiment K^-p at 10.1 GeV/c

2.1.1 Film exposures

The experimental data come from three separate exposures of hydrogen bubble chambers to the radio-frequency separated U5 beam of negative kaons at the CERN Proton Synchrotron. The beam was designed by P. Lazeyras et al. [1,2,3]. Fig. 2.1 illustrates the beam-layout used.

There are three main stages in the beam transport as indicated below:

A. Formation and momentum analysis:

The fast-ejected beam from the Proton Synchrotron hits a copper target producing a number of secondary particles of all types and momenta. The momentum selection of the secondary particles is achieved by using first a series of magnets "M" to bend the trajectories of the charged particles according to their momenta, and then the collimators "C" which reject all particles except those with the desired momentum. Focusing of the beam is obtained by means of the magnetic quadrupole lenses "Q".

B. Separation:

The momentum- analysed beam consists primarily of negative pions, kaons and muons. The number of antiprotons was negligible. The purpose of the radio-frequency separation is to select the K^- -mesons. The beam particles going through the radio-frequency cavities RF1 and RF3 are deflected by an oscillating electric field

$$E_1 = E_0 \sin \omega t \quad \text{in RF1}$$

and

$$E_3 = E_0 \sin \left\{ \omega (t - \tau) + \phi_{13} \right\} \quad \text{in RF3,}$$

where τ is a time delay dependent on the distance l between the cavities and particle velocity β : $\tau = l/\beta c$. The relative phase ϕ_{13} is adjusted to give effectively no deflection for the pions

and muons, which then are absorbed or degraded by the beam stopper "BS" placed in the centre of the beam cross section. The kaons are deflected around the beam stopper.

C. Final momentum analysis:

After the beam stopper, a series of collimators limit the number of secondary particles and reduce the muon contamination coming from the decay of kaons in flight. They also remove the low momentum degraded particles coming from the beam stopper. The quadrupoles and bending magnets serve to adjust the position and the shape of the beam entering the bubble chamber. Fig. 2.2 illustrates the optical properties of the beam in the horizontal and vertical planes.

The details of the three exposures, referred to as CERN experiments number 75, 10 and 12, respectively, are summarized in table 2.1.

TABLE 2.1

The 10.1 GeV/c K^- exposures

Experiment number	Date	Type of bubble chamber	Number of photographs	Average number of K^- tracks per photograph
75	Febr.-Apr. 1965	150 cm British HBC	200 000	5
10	August 1966	200 cm CERN HBC	70 000	6
12	Jan.-Febr. 1968	200 cm CERN HBC	210 000	8

For all three exposures the momentum of the K^- beam, determined by the radio-frequency separation, was $P_0 = 10.12$ GeV/c with a spread $\frac{\Delta P}{P_0} = \pm 0.6\%$ for experiments 75 and 10 and $\pm 0.25\%$ experiment 12.

The contamination of the beam entering the bubble chamber was estimated [4] to be about 3% of π^- and about 50-60% of μ^- , the latter coming from the K^- decaying in flight after the beam stopper. As the cross section for muon-proton interactions is very small in comparison with the cross section for K^-p interactions at 10 GeV/c, the μ^- contamination in the beam may be neglected. The contamination of π^- introduces a systematic error of 0.3% in the cross sections determination for $\bar{K}^0$ production.

2.1.2 Scanning, measuring and processing of the data

The exposed film was distributed to five European Laboratories taking part in the collaboration for the study of K^-p interactions at 10 GeV/c. These were: III Physikalisches Institut der Technischen Hochschule, Aachen (16% of the film), Institut für Hochenergiephysik der Deutschen Akademie der Wissenschaften zu Berlin, Zeuthen (9% of the film), CERN (51% of the film), Imperial College, London (9% of the film) and Institut für Hochenergiephysik der Österreichischen Akademie der Wissenschaften, Vienna (15% of the film).

In all laboratories the film was scanned twice by two different scanners for all K^-p interactions with an associated V^0 . A V^0 is the visible decay into two charged particles of a neutral strange particle. This neutral particle may be K^0 , $\bar{K}^0$, Λ or $\bar{\Lambda}$. Fig. 2.3 gives an example of such event with K^+ incoming.

About 88% of the film was scanned two or more times. The ionisation of all outgoing tracks in the primary vertex and in the V^0 decay was also estimated during the scanning. The estimated overall scanning efficiency was about 99% [4]. The length of the scanning area for events with a single V^0 was 72.6 cm and 101.4 cm and for events with more than one V^0 104 cm and 124 cm, for the British and CERN bubble chambers, respectively.

The selected events were measured on IEP's (Instruments for the Evaluation of Photographs). A sample of 50 000 pictures was measured on an automatic Hough-Powell Device, HPD (Flying Spot Digitizer). The precision of measurements of the coordinates of points in space was estimated to be about $120\ \mu$ for the IEP's measurements of the film from the 200 cm bubble chamber and $40\ \mu$ for the HPD measurements.

The events with more than one V^0 were measured on about 51% of the film only.

After measurement all the events were processed through the chain of standard bubble chamber programs THRESH and GRIND [5] which perform geometrical reconstruction of the tracks of the particles and which fit the various kinematic hypotheses. During the fitting procedure for every kinematic hypothesis to be tried, the measured track momenta were used in the attempt to satisfy energy-momentum conservation. The V^0 was fitted first and from the measured momenta of the decay particles a 3 constraint fit was performed giving the $\bar{K}^0$, Λ or $\bar{\Lambda}$ reconstructed momentum. This momentum was then used in the fitting procedure for the primary vertex. The ambiguity between $\bar{K}^0$ and Λ in the fits to V^0 was very small and usually was completely solved by the fit to the primary vertex. If a V^0 was identified as an electron pair, the event was tested according to the selection rules for events without V^0 . Events which failed the geometrical reconstruction tests or did not give an acceptable fit to any of the hypotheses of the various reaction channels were re-measured and re-processed. They amounted to about 29% of the total. About 3% of events failed the tests after the second re-measurement and were rejected as unmeasurable. The results of GRIND were checked for consistency with the track ionisation estimated during the scanning. A fit to a given hypothesis for a reaction channel was accepted if it was consistent with the ionisation of the tracks and if the probability of the fit was larger than 1% for four-constraints fits - 4C (no neutral particle other than K^0 , all masses of charged particles assumed

and their momenta taken as measured) or larger than 5% for one-constraint fits - 1C (one additional known neutral particle with assumed mass and unknown momentum). For 1C-fits and NOFIT (more than one neutral particle, no restriction on mass) a cut on the laboratory momentum of protons at 2 GeV/c was imposed in order to reduce the number of false hypotheses with a fast proton instead of a fast π^+ . Only when no other hypothesis was acceptable this restriction was omitted. This cut may introduce rather small errors in the determination of cross sections for the reaction channels with many neutral particles but has no influence on the study of $\bar{K}^0$ production. For the events with acceptable 4C-fits, the 1C-fits and the NOFIT hypotheses were rejected. Similarly for the events with acceptable 1C-fits the NOFIT hypotheses were neglected. A maximum of three hypotheses per event were accepted. After the decision on the reaction channel (channels) was taken, the events were passed through the program SLICE to produce the Data Summary Tapes-DST. In order to make the handling of the data easier, the information concerning all events with at least one $\bar{K}^0$ decaying inside the chamber was stored in a condensed form on one magnetic tape identified as the MINI-DST.

2.1.3 Hypothesis and decay weights

The kinematic fitting procedure of well measured events often gives more than one acceptable hypothesis for an event, since often several different configurations of particles with the given momenta are equally probable. The main source of this ambiguity is the difficulty in distinguishing by ionisation between a proton and a π^+ at momenta above 1.5 GeV/c. The usually more troublesome ambiguity between K^- and π^- does not occur with the events with a visible decay of K^0 . A maximum number of 3 hypotheses was accepted for an event. The weight of hypothesis is given by $1/n$ where n is the number of accepted hypotheses. The average $1/n$ weight for events with K^0 decay is 0.85.

In addition, for each event, the $\bar{K}^0$ decay weight was calculated. This takes into account the probability of observing a $\bar{K}^0$ decay in different parts of the chamber. This weight is bigger than 1, the average being 1.075.

The weight of the hypothesis was then multiplied by the $\bar{K}^0$ decay-weight, to obtain the total weight for the hypothesis considered. For events with more than one strange particle decay the total weight was given by the product of hypothesis weight and all decay-weights.

The average total weight for a hypothesis is $W = 0.92$. As a check of the correctness of the decay weight calculation for the $\bar{K}^0$, the mean life time of $\bar{K}^0$ may be calculated. The decay probability of a particle with mean life time τ after the time t is given by

$$P(t) = \frac{1}{\tau} \exp(-t/\tau) = \frac{1}{\tau} \exp\left(-\frac{\ell m}{pc} / \tau\right),$$

where p is the particle momentum, m is its mass and ℓ is its path before decay. The distribution, corrected by the decay weight, of the quantity ℓ/p for the $\bar{K}^0$ is presented in fig. 2.4. The mean life time calculated from this distribution is equal to $\tau_{\text{exp}} = 0.81 \pm 0.04 \cdot 10^{-10} \text{ sec}$ which may be compared with the value of $\tau = 0.862 \pm 0.006 \cdot 10^{-10} \text{ sec}$ given in the Particle Data Tables [6]. The numbers of events with $\bar{K}^0$ decay seen and the number of hypotheses are given in table 2.2. The numbers of events contributed to the total sample by the different laboratories in the Collaboration are given in table 2.3.

TABLE 2.2

Events with $\bar{K}^0$ decays seen in the hydrogen bubble chamber

Experiment number	Number of events	Number of hypotheses	Corrected number of events	Percentage
75	5 789	7 063	6 348	34.8%
10	2 793	3 369	2 949	16.2%
12	8 376	9 350	8 932	49.0%
Total	16 958	19 782	18 229	100.0%

TABLE 2.3

Contributions to the total sample from different laboratories

Laboratory	Aachen	Berlin	CERN	London	Vienna
Number of events	2 966	1 559	9 340	1 656	2 708

2.2 Experiment K_p^+ at 8.2 GeV/c

2.2.1 Film exposures

The film comes from two exposures of the 200 cm CERN hydrogen bubble chamber to the radio-frequency separated K^+ -beam at the CERN Proton Synchrotron. The same U5 beam set-up was used as described in section 2.1.1. During the first run in September 1966, which has the CERN experiment number 08, about 120 000 photographs were taken; during the second run in January 1967 (experiment 09) about 100 000 pictures.

The momentum of the K^+ beam was equal to 8.25 GeV/c with a spread, $\frac{\Delta P}{P}$, of about 0.25%. The contamination of the beam was estimated [7] to be: about 17% of μ^+ , about 3% of protons and about 0.3% of π^+ . The proton and π^+ contamination introduced a systematic error of about 1% to the cross-section determinations. The pictures were taken with 8 K^+ tracks per photograph on the average.

2.2.2 Scanning, measuring and processing of the data

The exposed film was scanned, measured and processed in two collaborating laboratories: CERN (about 86% of the film) and Laboratoire Interuniversitaire Belge des Hautes Energies, Bruxelles (about 14% of the film). The film was scanned twice for all the K^+p interactions and in particular for events with a V^0 , with a scanning efficiency of about 98% [7]. The ionisation of the tracks was also estimated. The length of the scanning area for events with a V^0 was equal to 142 cm. All events with at least one V^0 were measured in CERN on IEPs and on a similar device called ENETRA in Bruxelles. For both types of instruments the precision of measurements of points in space is of about 120 μ .

After measurements, the events were processed through the chain of standard THRESH-GRIND-SLICE programs as described in sect. 2.1.2. Events which failed the geometrical reconstruction tests or did not give an acceptable fit to any of the reaction channel hypotheses were sent for re-measurement. About 25% of the events were remeasured with a maximum of two re-measurements per event. The remaining events which were for some reason unmeasurable and were rejected, constitute about 1% of the total sample.

The results of GRIND were checked on the scanning table against the ionisation of the tracks. Again, because of the ambiguity in distinguishing a proton from a π^+ at higher momenta, it often happened that more than one hypothesis of reaction channels fulfilled the tests of energy-momentum conservation. The hypothesis of a given reaction channel was accepted if it agreed with the ionisation of the tracks and if, for 4C and 1C fits, the probability of the fit was greater

than 0.1%. A maximum of 3 hypotheses chosen for having the highest probabilities were accepted for 4C and 1C fits. For the multineutral events i.e. events with more than one neutral particles other than K_1^0 , which gave only the NOFIT hypotheses, one hypothesis per event was accepted. Although this procedure may introduce a serious bias in the detailed study of a particular reaction channel, it has no bearing upon the study of K^0 production, where we are interested in the sum of all reaction channels, and we do not pay attention to what is actually produced together with the K^0 meson.

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FIGURE CAPTIONS

- 2.1. Layout of the U5 RF separated beam
- 2.2. Ray diagram for undeviated particles in the horizontal and vertical plane of the U5 RF separated beam.
- 2.3. Photograph of an event with a V^0 in the bubble chamber
- 2.4. Distribution of the quantity l/p i.e. ratio of the path of the $\bar{K}^0$ to its fitted momentum, corrected by the decay weight. The solid line represent fit to the mean life time as described in the text.

Fig. 2.1

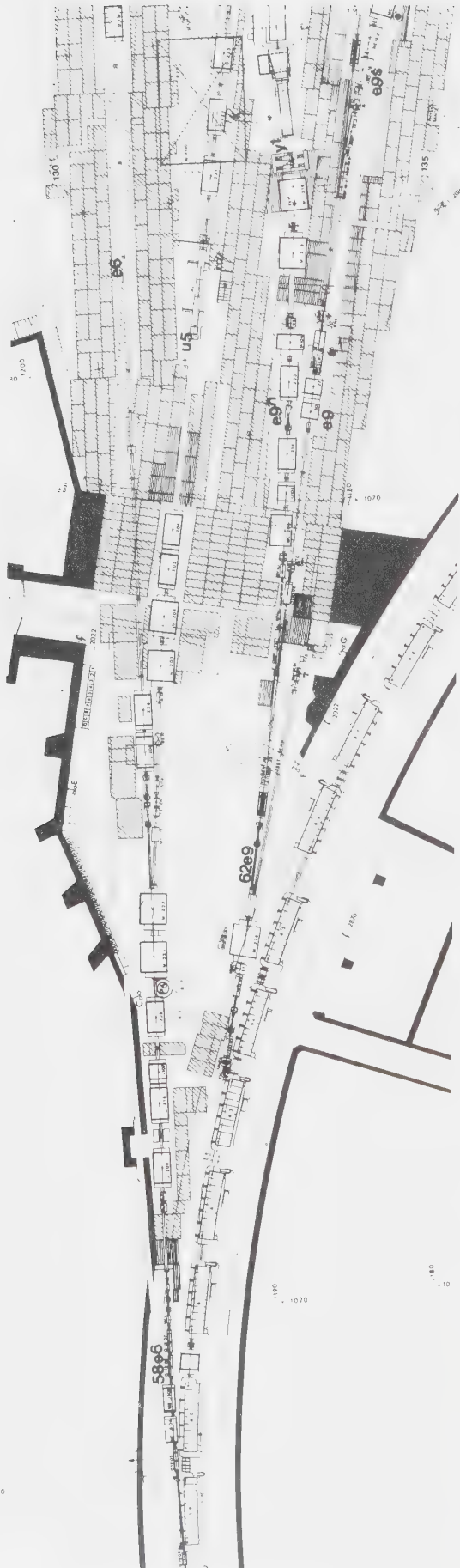
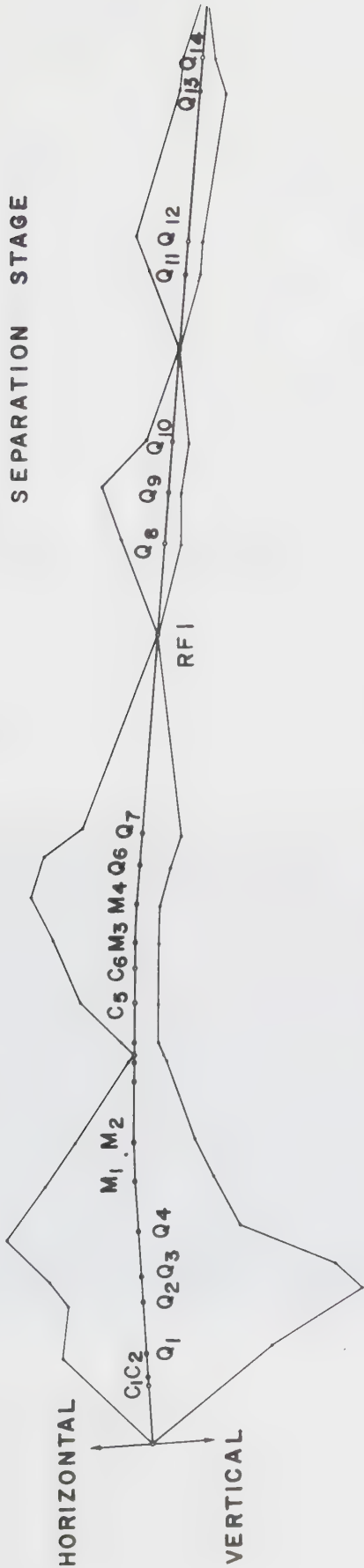


Fig. 2.2

FORMATION AND MOMENTUM
ANALYSIS STAGE



SEPARATION STAGE

FINAL MOMENTUM ANALYSIS STAGE



Fig. 2.3

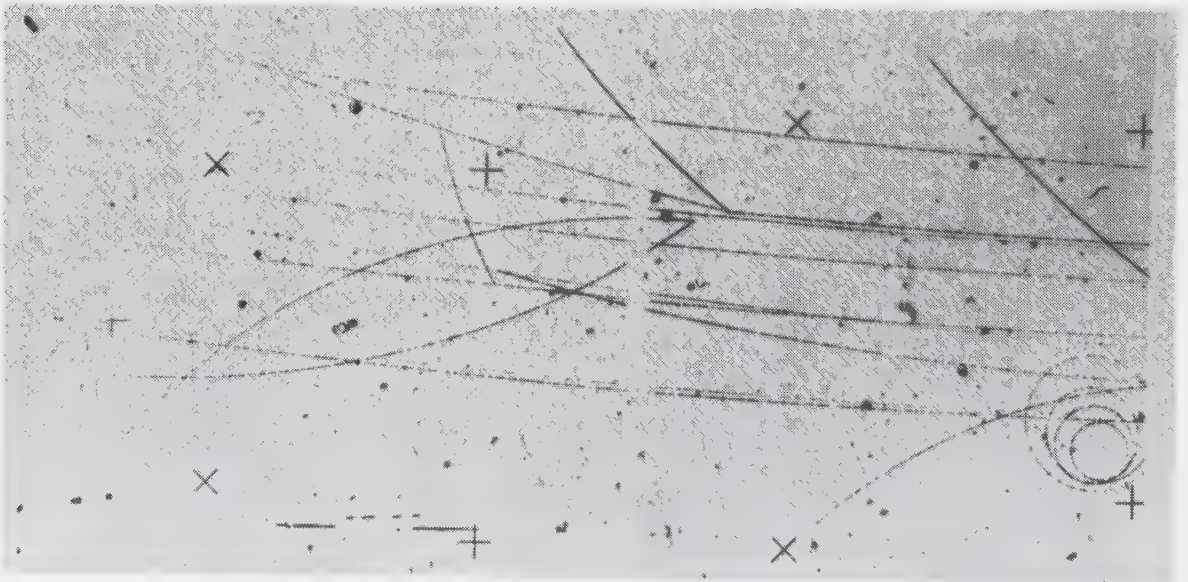
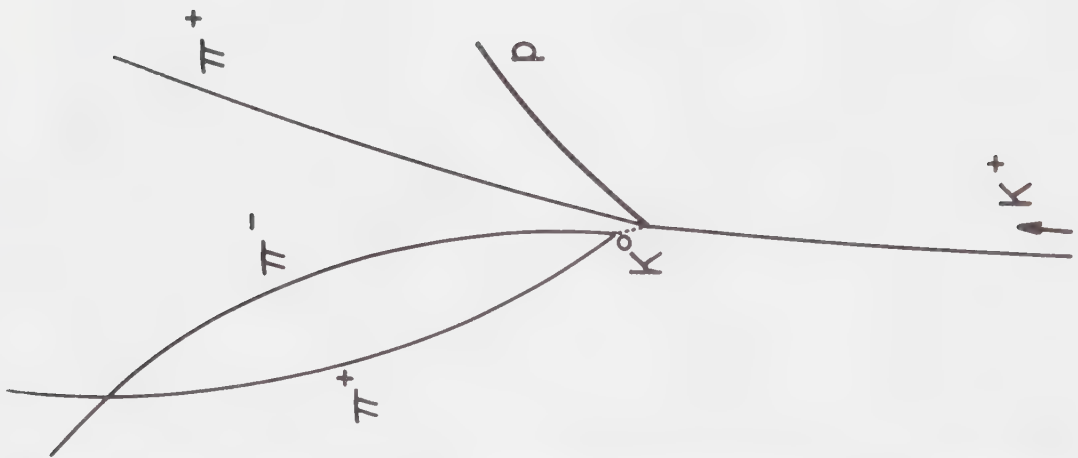
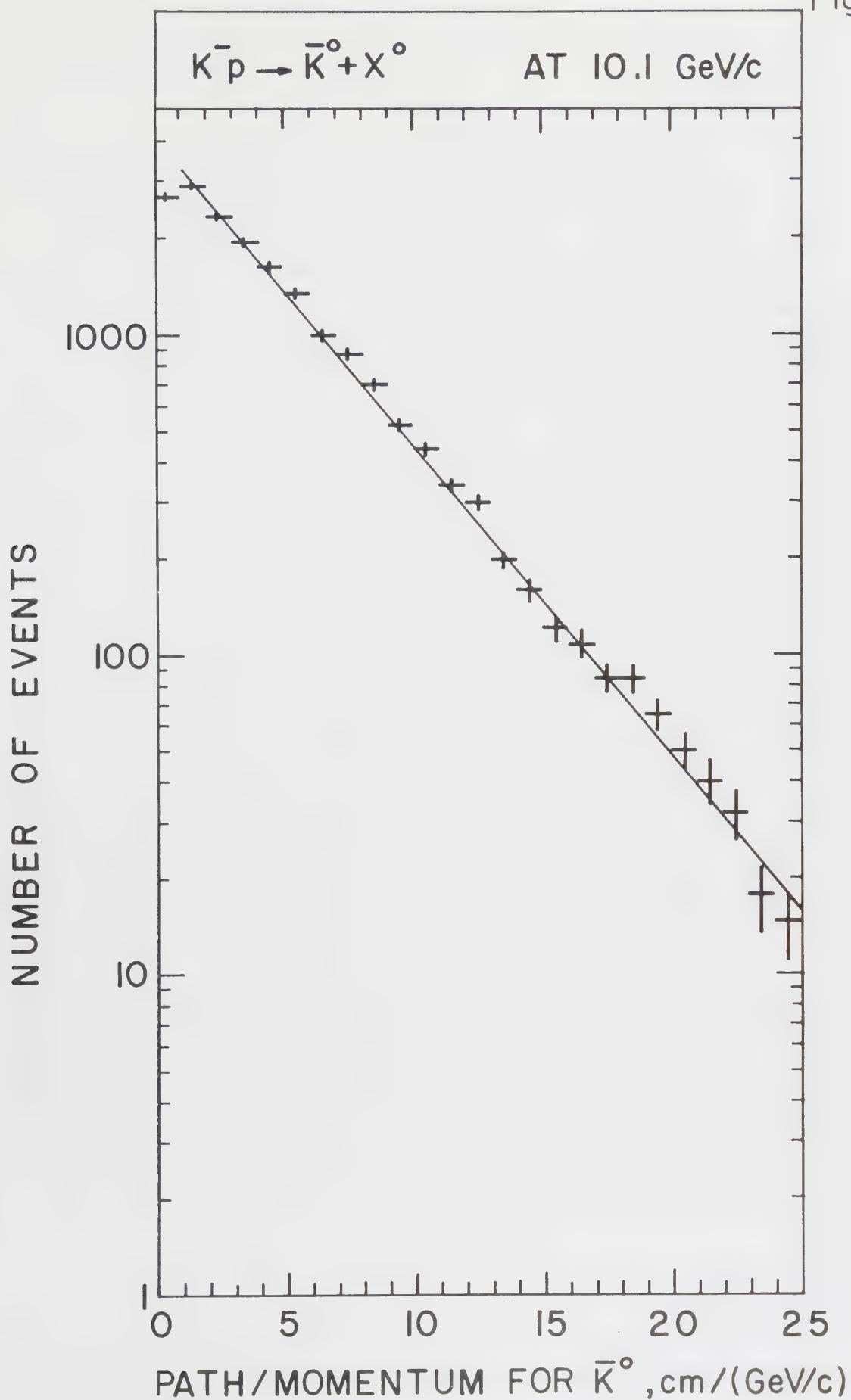


Fig. 2.4



3. CROSS SECTIONS

3.1 Topological cross sections

The cross sections in bubble chamber experiments can be normalised by comparing the total cross sections with the values obtained from counter experiments. In order to minimise the systematic error in the interpolation of the cross section values at the energy considered these numbers were obtained from the fit of a straight line to the log-log plot of the data available, collected in a compilation of the total K^-p and K^+p cross sections [1] . The interpolation of the data gave values of $\sigma_{TOT} = 22.6 \pm 0.2$ mb for the total cross sections for K^-p interactions at 10.1 GeV/c and $\sigma_{TOT} = 17.2 \pm 0.1$ mb for K^+p interactions at 8.2 GeV/c. These two numbers were the starting points for calculation of the topological cross sections i.e. the cross sections for events with a defined number of charged particles in the final state.

For the K^-p experiment the total number of events of each topology found in scanning was corrected for changes in topology after the measurements, e.g. when a V^0 was determined to be an electron pair, and for scanning losses. The latter are rather small for events with many charged particles but are considerably larger for 0-prong and 2-prong events. In particular for the 0-prong events the scanning losses are difficult to estimate and the number of events produced was estimated from the number of 0-prong V^0 events. The number of 2-prong events was also corrected for the losses due to small angle elastic scatters.

The topological cross sections were then obtained by dividing the total cross section proportionally to the corrected numbers of events of each topology. The topological cross sections for events with a visible V^0 in the final state and the topological microbarn equivalents (i.e. the values obtained by dividing each topological

cross section by the number of events actually measured with that topology) are given in table 3.1.

For K^+p experiment similar procedure was applied to restricted sample of events. The topological cross sections for events with V^0 in the final state are also given in table 3.1.

That the cross sections for V^0 production are larger in K^-p than in K^+p reactions is caused mainly by the frequent production of particles in K^-p reactions and these have a higher decay rate into charged particles.

TABLE 3.1

The topological cross sections

Topology	K^-p at 10.1 GeV/c		K^+p at 8.2 GeV/c
	σ (mb)	$\mu\text{b/event}$	σ (mb)
0-prongs V^0	0.277 ± 0.010	0.164	
2-prongs V^0	1.768 ± 0.021	0.130	0.939 ± 0.050
4-prongs V^0	1.477 ± 0.018	0.139	0.726 ± 0.045
6-prongs V^0	0.322 ± 0.015	0.207	0.084 ± 0.015
8-prongs V^0	0.021 ± 0.004	0.392	
10-prongs V^0	0.002 ± 0.001	0.580	
$\geq 2 V^0$	0.438 ± 0.040		0.090 ± 0.048

All errors quoted above are statistical only and correspond to one standard deviation.

3.2. Cross sections for the various reaction channels with K^0

Once the topological microbarn equivalent was determined, the cross section for a particular reaction channel was obtained by multiplying the topological microbarn equivalent by the number of events assigned to a given hypothesis. The appropriate corrections were applied for the losses and changes in reaction hypotheses due to the restrictions on probability and missing mass imposed during the fitting procedure as described in chapter 2. Also a correction was made for charged decays of K^0 mesons which occur and are not measurable, either because they occur too near to the interaction vertex, or because they occur outside the visible region of the chamber. Due to the different life times we observe in the bubble chamber decays of K_S^0 only and not of K_L^0 . In addition the neutral decay modes of K_S^0 , i.e. $K^0 \rightarrow 2\pi^0$, are also not detectable in the bubble chamber. Therefore, all the cross sections were multiplied by the factor $1.46 \times 2 = 2.92$ [2] in order to correct for the undetected decays of K^0 . The numbers of events corrected for decay weights and the values of the cross sections for different reaction hypotheses are given in table 3.2a for the K^-p experiment.

The cross sections for different reaction hypotheses for the experiment K^+p at 8.2 GeV/c were determined in a similar way and are given in table 3.2b.

It is interesting to note that the fraction of the inelastic cross section associated with K^0 production is close to 40% for both experiments ($\sigma_{K^0}/\sigma_{inel} = 5.76 \text{ mb}/13.8 \text{ mb} = 0.417$ for K^+p interactions at 8.2 GeV/c, $\sigma_{K^0}/\sigma_{inel} = 7.58 \text{ mb}/19.4 \text{ mb} = 0.390$ for K^-p interactions at 10.1 GeV/c). These values are compared in fig. 3.1. with corresponding results from K^+p experiment at 3, 3.5 and 5 GeV/c [3]. As can be seen the fraction of inelastic Kp reactions giving K^0 mesons is approximately constant between 3 and 10 GeV/c incoming momentum. This may be perhaps taken as an evidence that the probability of the kaon charge exchange is constant in the energy range studied. Similar values were obtained for the probability of the $p \rightarrow n$ charge exchange in πp interactions at 8, 10 and 16 GeV/c and K^-p interactions at 10.1 GeV/c [4].

TABLE 3.2a.

The reaction channels cross sections for 10.1 GeV/c K^-p experiment

Topology	Reaction hypothesis	Number of events	σ (mb)
0-prongs $\bar{K}^0$	$K^-p \rightarrow n\bar{K}^0$ $\rightarrow K^0 Z^0(a)$	67.8 1162.6	0.040 ± 0.006 0.570 ± 0.015
2-prongs $\bar{K}^0$	$\rightarrow \bar{K}^0 \pi^-$ $\rightarrow p\bar{K}^0 \pi^- \pi^0$ $\rightarrow n\bar{K}^0 \pi^+ \pi^-$ $\rightarrow p\bar{K}^0 \pi^- Z^0$ $\rightarrow \bar{K}^0 \pi^+ \pi^- Z^0$	564.5 1655.4 885.6 1784.0 4563.9	0.22 ± 0.03 0.63 ± 0.09 0.33 ± 0.04 0.69 ± 0.09 1.78 ± 0.11
4-prongs $\bar{K}^0$	$\rightarrow p\bar{K}^0 \pi^+ \pi^- \pi^-$ $\rightarrow p\bar{K}^0 \pi^+ \pi^- \pi^- \pi^0$ $\rightarrow n\bar{K}^0 \pi^+ \pi^+ \pi^- \pi^-$ $\rightarrow p\bar{K}^0 \pi^+ \pi^- \pi^- Z^0$ $\rightarrow \bar{K}^0 \pi^+ \pi^+ \pi^- \pi^- Z^0$	788.0 1377.1 661.8 1656.4 2219.8	0.33 ± 0.04 0.57 ± 0.04 0.27 ± 0.03 0.69 ± 0.05 0.93 ± 0.06
6-prongs $\bar{K}^0$	$\rightarrow p\bar{K}^0 \pi^+ \pi^+ \pi^- \pi^- \pi^-$ $\rightarrow p\bar{K}^0 \pi^+ \pi^+ \pi^- \pi^- \pi^- \pi^0$ $\rightarrow n\bar{K}^0 \pi^+ \pi^+ \pi^+ \pi^- \pi^- \pi^-$ $\rightarrow p\bar{K}^0 \pi^+ \pi^+ \pi^- \pi^- \pi^- Z^0$ $\rightarrow \bar{K}^0 \pi^+ \pi^+ \pi^+ \pi^- \pi^- \pi^- Z^0$	153.4 227.6 66.6 169.1 201.1	0.096 ± 0.009 0.141 ± 0.009 0.039 ± 0.006 0.102 ± 0.009 0.123 ± 0.009
8-prongs $\bar{K}^0$	$\rightarrow p\bar{K}^0 \pi^+ \pi^+ \pi^+ \pi^- \pi^- \pi^- \pi^-$ $\rightarrow p\bar{K}^0 \pi^+ \pi^+ \pi^+ \pi^- \pi^- \pi^- \pi^- \pi^0$ $\rightarrow n\bar{K}^0 \pi^+ \pi^+ \pi^+ \pi^+ \pi^- \pi^- \pi^- \pi^-$ $\rightarrow p\bar{K}^0 \pi^+ \pi^+ \pi^+ \pi^- \pi^- \pi^- \pi^- Z^0$ $\rightarrow \bar{K}^0 \pi^+ \pi^+ \pi^+ \pi^+ \pi^- \pi^- \pi^- \pi^- Z^0$	8.8 3.7 0.5 4.6 6.2	0.009 ± 0.003 0.004 ± 0.002 ≤ 0.001 0.005 ± 0.002 0.006 ± 0.002
ALL topologies with $\bar{K}^0$		18228.	7.58 ± 0.18

(a) Z^0 denotes two or more neutral particles

TABLE 3.2.b

The reaction channels cross sections for 8.2 GeV/c K^+p experiment

Topology	Reaction hypothesis	Number of events	σ (mb)
2-prongs K^0	$K^+p \rightarrow pK^0\pi^+$	876.3	0.46 ± 0.03
	$\rightarrow pK^0\pi^+\pi^0$	2516.9	1.33 ± 0.09
	$\rightarrow nK^0++$	495.4	0.26 ± 0.02
	$\rightarrow pK^0\pi^+Z^0(a)$	2022.2	1.05 ± 0.07
	$\rightarrow K^0\pi^+\pi^+Z^0$		
4-prongs K^0	$\rightarrow pK^0\pi^+\pi^+-$	806.2	0.42 ± 0.03
	$\rightarrow pK^0\pi^+\pi^+\pi^-\pi^0$	1609.6	0.84 ± 0.06
	$\rightarrow nK^0\pi^+\pi^+\pi^+-$	357.7	0.18 ± 0.01
	$\rightarrow pK^0\pi^+\pi^+Z^0$	946.3	0.65 ± 0.04
	$\rightarrow K^0\pi^+\pi^+\pi^+Z^0$		
6-prongs K^0	$\rightarrow pK^0\pi^+\pi^+\pi^+-$	157.5	0.08 ± 0.01
	$\rightarrow pK^0\pi^+\pi^+\pi^+\pi^-\pi^0$	273.3	0.13 ± 0.01
	$\rightarrow nK^0\pi^+\pi^+\pi^+\pi^+-$	51.8	0.04 ± 0.01
	$\rightarrow pK^0\pi^+\pi^+\pi^+Z^0$	77.7	0.06 ± 0.01
	$\rightarrow K^0\pi^+\pi^+\pi^+\pi^+Z^0$		
ALL topologies with K^0		10479.	5.76 ± 0.33

(a) Z^0 denotes two or more neutral particles

3.3 Statistical isospin weights

In the year 1950 Fermi [5] proposed a statistical model for the description of high energy collisions. Subsequent studies [6] have shown that the model fails to describe many important features of hadron interactions, mainly connected with the peripheral character of particle production. However, some average quantities, e.g. the cross sections for the production of given number of particles are well described by this model. The basic assumption of the statistical model is the equality of the probabilities of observing different isospin final states of a given multiplicity, provided that charge and total isospin are conserved. This assumption allows a calculation of the relative probabilities for different charge configurations of the produced particles, and consequently from the cross section for one reaction channel the cross sections for all other possible reaction channels with the same number of particles in the final state can be calculated. The formula for calculating the isospin weights was derived by Cerulus [8]:

$$P(t_o, m_o) = (t_o + \frac{1}{2}) 2^{-\sum m_i} \int_{-1}^{+1} dx (1+x)^{\sum m_i} \prod_{i=1}^{n-1} p_{t_i, -m_i}^{o, 2m_i}(x)$$

where t denotes the isospin, m the modulus of its third component and the indices 0 and i indicate the initial state and i -th particle, respectively.

$p_{t-m}^{o, 2m}(x)$ are the Jacobi polynomials.

For practical purposes the isospin weight factors were calculated and tabulated by Bartke [9].

3.4. Multiplicity distributions

Using the statistical isospin weights described in 3.3., cross sections were calculated for every possible reaction channel with K^0 in the final state. For the channels with odd number of pions the cross sections were determined on the basis of 4C-fitted reaction channels. For the channels with even number of pions, the 1C-fits were used, which allowed two independent estimates of the cross sections to be made, starting either from the reactions with one π^0 or from the reactions with a neutron in the final state. For an additional check, the topological cross sections for reactions with $\bar{K}^0$ in the final state were calculated. They are compared in table 3.3. with the measured topological cross sections for the 10.1 GeV/c K^-p experiment. As can be seen, the agreement between the measured and calculated values is satisfactory.

TABLE 3.3.

Topological cross sections for events with $\bar{K}^0$ for the 10.1 GeV/c K^-p experiment

Topological	σ (mb) measured	σ (mb) calculated
0-prongs $\bar{K}^0$	0.61 ± 0.06	0.55 ± 0.06
2-prongs $\bar{K}^0$	3.66 ± 0.24	3.50 ± 0.30
4-prongs $\bar{K}^0$	2.79 ± 0.17	2.73 ± 0.20
6-prongs $\bar{K}^0$	0.50 ± 0.03	0.57 ± 0.05
8-prongs $\bar{K}^0$	0.03 ± 0.01	0.05 ± 0.02

In fig. 3.2 the cross sections for various multiplicities obtained by summing the cross sections for all the channels with the same number of particles in the final state, are presented for the K^- and K^+ experiments. Although the average multiplicity, does not differ very much (5.3 and 5.6 for K^+p and K^-p experiments respectively), the shape of the distributions is significantly different. This is partly due to the fact, that for the K^-p experiment, the distribution starts for the number of pions equal to zero which corresponds to the charge exchange reaction (not possible for the particular class of reactions considered for K^+p interactions), and is also much broader.

The statistical-like models imply [10,11] that multiplicity distributions should be well described by a Poisson distribution. For the case of Kp experiments, because of conservation of baryonic number and strangeness, a Poisson distribution should be observed for the number of pions produced together with the K^0 and the nucleon. This distributions are shown in fig. 3.2 as the solid lines.

Recently Czyzewski and Rybicki [12] advocated, on the basis of a large collection of experimental data, the use, instead of the normal Poisson distribution, of a generalized Poisson distribution in terms of the two variables

$$x = \frac{n - \langle n \rangle}{D} \quad \text{and} \quad y = D \cdot P(n)$$

where D is the dispersion of the distribution $D = (\langle n^2 \rangle - \langle n \rangle^2)^{1/2}$, $P(n)$ is the probability of observing n pions in the final state, and the relation between x and y is given by the formula

$$y = d e^{-d^2} \frac{d^{2(dx + d^2)}}{\Gamma(dx + d^2 + 1)},$$

Γ being the gamma function and $d = 1.8$ being the constant which the authors obtained from fitting experimental data.

The predictions of the Czyzewski-Rybicki formula for the reactions $K^{\pm}_p \rightarrow K^0 N + n\pi$ are shown in fig. 3.2 as the dashed lines. As may be seen, the Poisson distribution and the Czyzewski-Rybicki formula do not differ very much for the K^+_p experiment and both describe the data rather well. For the K^-_p experiment, the agreement is not so good, however the Czyzewski-Rybicki formula describes the data much better than the Poisson distribution.

In fig. 3.3 the average charge multiplicity n_{CH} i.e. the average number of charged particles for the reactions $K^+_p \rightarrow K^0 + X^{++}$ and $K^-_p \rightarrow \bar{K}^0 + X^0$ is presented as the function of the effective mass squared of the system X. The fits of these distributions with formulae

$$\frac{d\langle n_{CH} \rangle}{dMM^2} = A + \log (MM^2) \quad (3.1)$$

and

$$\frac{d\langle n_{CH} \rangle}{dMM^2} = C \cdot (MM^2)^D \quad (3.2)$$

were performed and the results are given in table 3.4. It is interesting to note that the formula (3.2) gives much better description of the data for both the reactions studies.

TABLE 3.4

Reaction	A	B	X^2/DF	C	D	X^2/DF
$K^+_p \rightarrow K^0 + X^{++}$	0.82 ± 0.07	0.99 ± 0.03	26.1/16	1.35 ± 0.04	0.36 ± 0.02	16.8/16
$K^-_p \rightarrow \bar{K}^0 + X^0$	0.28 ± 0.05	1.06 ± 0.02	96.5/26	0.95 ± 0.02	0.44 ± 0.01	44.6/26

Until the last few years it was generally observed that the total average charged multiplicity in hadron interactions is a power function of the square of the total c.m. energy s . However, the recent, yet unconfirmed results from the Echo Lake experiment [13] indicate the possibility of a logarithmic dependence on s .

$$\langle n_{CH} \rangle = a + b \log s$$

Such dependence was also obtained from the multiperipheral model [14]. If one can apply the multiperipheral model to the K^0 producing reactions, at fixed c.m. energy, by simple analogy, the average charged multiplicity should be logarithmically dependent on MM^2 i.e. on the square of the total c.m. energy of the system X in its rest frame. The results presented seems to favor the formula 3.2 at variance with preliminary results from πp experiments [15].

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FIGURE CAPTIONS

- 3.1 Ratio of K^0 production cross section to total inelastic cross section as a function of incident laboratory momentum for K^+p and K^-p interactions.
- 3.2. The cross section as a function of the number of pions produced together with K^0 and a baryon. The solid lines represent the Poisson distribution normalised to the total cross section for the K^0 production, the dashed lines are the predictions of Czyzewski-Rybicki [10] formula.
- 3.3 Average number of charged particles produced together with K^0 as a function of missing mass squared.

Fig.3.1

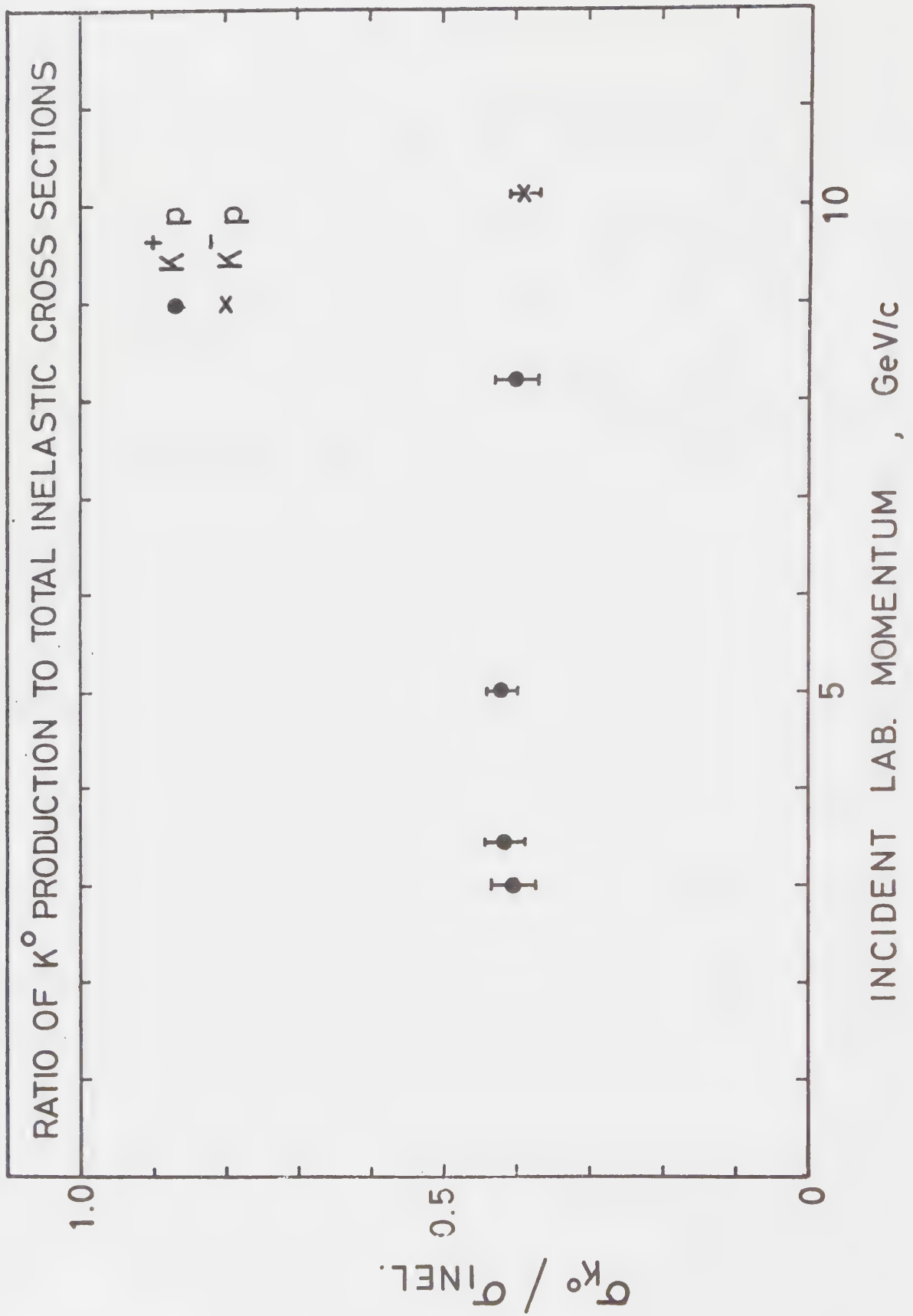
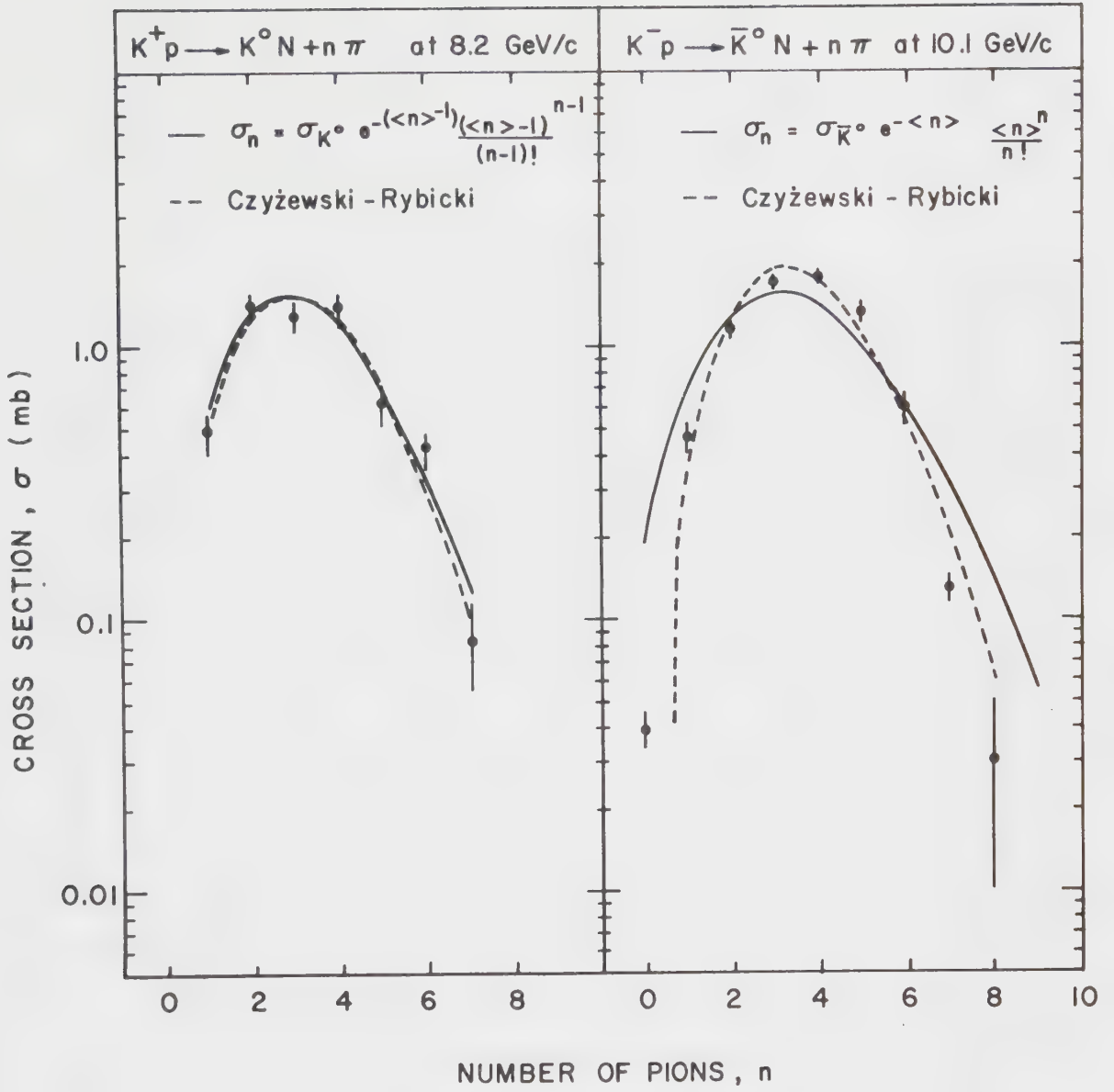


Fig. 3.2



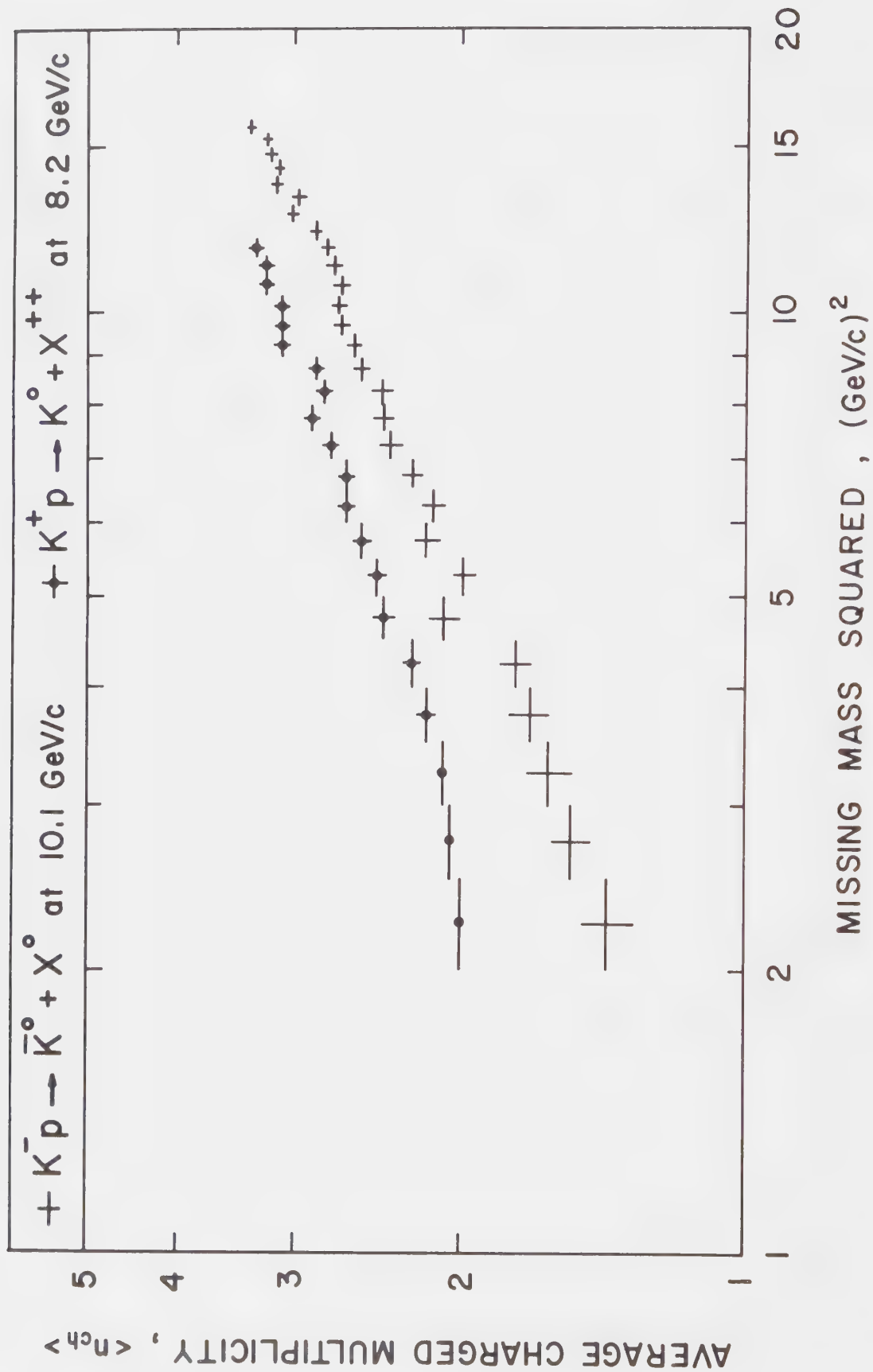


Fig. 3.3

4. DISTRIBUTION OF K^0 -MESONS

At a given laboratory momentum, two independent variables are sufficient to describe single particle production. The choice of variables depends usually on experimental arrangements or specific purposes. In the following section we shall present the distributions of K^0 -mesons in terms of pairs of variables used most often.

4.1. Laboratory momentum spectra of K^0 -mesons

In fig. 4.1. the double differential cross section distributions $d^2\sigma/dp_{LAB} d\Omega_{LAB}$ for K^0 -mesons produced in K^+p and K^-p interactions are presented as functions of the laboratory momentum for various intervals of the emission angle θ_{LAB} . Since the interactions of unpolarized hadrons are cylindrically symmetric, we have integrated the distributions over the azimuthal angle ϕ . Because of the relatively small number of events, we have integrated in certain regions over rather large production angle; therefore, in order to correct for this, the weight factor $W = 1/2\pi \sin\theta_{LAB}$ was introduced for each event.

This presentation of the data is often used in counter experiments. It is worth noticing that although the statistical significance of bubble chamber data is in general much smaller than in a typical counter experiment, the bubble chamber has the advantage of covering the full solid angle of particle emission.

In K^+p interactions, a structure may be observed near the kinematic limit, for the emission angles between 20 and 100 milliradians. This structure may be explained by the occurrence of the two-body reaction $K^+p \rightarrow K^0\Delta^{++}$. No such evident structure is however observed in the corresponding $\bar{K}^0$ spectra from the K^-p interactions, presumably because of the much smaller cross section (in comparison with the total) for the reaction $K^-p \rightarrow \bar{K}^0\Delta^0$. In addition the Δ^0 production may be masked by the copiously produced $N_{1/2}^0$ isobars. The laboratory momentum spectra of K^0 -mesons integrated over the emission angle

(fig. 4.2.) present basically the same features.

The hypothesis of limiting fragmentation proposed by Benecke et al. [1] asserts that in a collision between two hadrons, the target and the projectile separately undergo fragmentation. The momentum spectrum of the fragments from the target approach with increasing energy a limiting distribution in the target rest frame (laboratory system) and similarly for the fragments of the projectile a limiting distribution is approached in the projectile rest frame (mirror system). This hypothesis has already found confirmation for the fragmentation of the target proton even at present accelerators energies [2]. In Kp collisions at the energies studied the majority of the K^0 -mesons comes from the fragmentation of the projectile kaons. The longitudinal momentum distributions of K^0 -mesons, in the mirror system for K^+p at 5 GeV/c [3] and 8.2 GeV/c and K^-p at 10.1 GeV/c experiments are shown in fig. 4.3. Unfortunately, the energy range is rather small for testing the hypothesis of limiting fragmentation. The distributions shown are, however, very similar to one another, thus indicating that distributions of the fragments of K-mesons are not strongly dependent on the charge of the kaon and that perhaps at higher energies the limiting distribution may be obtained.

4.2. Centre-of-mass momentum spectra

The most commonly used pair of variables which describe single particle distributions is the centre-of-mass longitudinal and transverse momentum. In particular, the study of these distributions in inclusive reactions has arisen new interest in the light of scaling and limiting fragmentation hypotheses.

In fig. 4.4. the distributions of the transverse momentum squared of K^0 's produced in K^+p and K^-p interactions are presented. Fits to an exponential function of the form

$$\frac{d\sigma}{dp_1^2} = (\text{const}) \cdot e^{-Ap_1^2} \quad (4.1.)$$

and to the Cocconi-Koester-Perkins formula [4]

$$\frac{d\sigma}{dp_{\perp}^2} = (\text{const}) \cdot e^{-Bp_{\perp}} \quad (4.2)$$

were performed in the region of $p_{\perp}^2 < 0.6 \text{ (GeV/c)}^2$. The values of the fitted parameters are given in table 4.1. with the χ^2 -probabilities and the degrees of freedom. As can be seen, the exponential form (4.1) seems to fit the data better.

TABLE 4.1

The fitted values of the exponential parameters used
in formulas 4.1 and 4.2

	$A, (\text{GeV/c})^{-2}$	χ^2/DF	$B, (\text{GeV/c})^{-1}$	χ^2/DF
$K^+ p \rightarrow K^0 + X^{++}$	5.55 ± 0.08	49/28	4.36 ± 0.05	236/28
$K^- p \rightarrow \bar{K}^0 + X^0$	4.79 ± 0.05	75/28	3.89 ± 0.04	267/28

In figs 4.5a) and c) the average transverse momentum of K^0 produced is plotted as a function of its longitudinal momentum. The well known sea-gull effect [5] i.e. the dip near the value of $p_L^* = 0$ may be explained at least in a good part as a phase-space effect. However, this dip remains after taking the phase-space into account, as can be seen in figs 4.5b) and d). The average transverse momentum for the $\bar{K}^0$ produced in $K^- p$ interactions at 10.1 GeV/c is $\langle p_{\perp} \rangle = 0.418 \pm 0.002 \text{ GeV/c}$.

In fig. 4.6 the longitudinal momentum distributions are plotted in terms of the reduced longitudinal momentum variable $x = p_L^*/p_{\text{max}}^*$ introduced by Feynman [6]. The distributions are similar in shape for both reactions, They are strongly asymmetric around $x = 0$, decreasing steeply with increasing negative values of x and rather slowly with positive x values. The peak near the value of $x = +1$ for the K^0 's from the $K^+ p$ interactions is the reflection of strong Δ^{++} production.

When comparing these distributions with the corresponding distributions of protons [7] and pions [8] produced in proton-proton collisions, one notices that the K^0 -mesons present a behaviour intermediate between that of the protons (leading particles), for which the x distributions are essentially flat and that of the pions (produced particles) for which the x distributions decrease rapidly with increasing longitudinal momentum. The x distribution for K^0 mesons produced in pp collisions [9] has a shape similar to that for produced pions. The K^0 -mesons from Kp interactions seem, therefore, to present some leading particle behaviour, but to a smaller extent than for protons.

The scaling hypothesis discussed in section 1 suggests that the reduced longitudinal momentum distributions of particles produced should become energy independent at asymptotic energies after taking into account the phase-space effects. In fig. 4.7. the invariant reduced longitudinal momentum distributions are compared with the corresponding data at other energies. The K^-p data at 4.2 GeV/c come from the Amsterdam-Nijmegen Collaboration [10] and K^+p data at 5 GeV/c from the CERN-Brussels Collaboration [3]. At the energies considered, most of the K^0 's originate from the fragmentation of the incoming kaon and only a small contribution is derived from the strangeness production mechanism, therefore, in terms of Feynman ideas, these reactions are "undeveloped" inclusive reactions [11]. Still it is interesting to note that in first approximation the distributions are similar to one another not only in shape but also in absolute values indicating, that these distributions depend very weakly on the charge of incoming kaon and that at higher energies one may expect scaling for this class of reactions.

Similar effect may be observed in fig. 4.8. in terms of the longitudinal rapidity variable y :

$$y = \frac{1}{2} \ln \frac{E + P_{||}}{E - P_{||}}$$

where E denotes the energy of the neutral kaon. This variable stretches the central region of longitudinal momentum distribution near $x = 0$ and shortens

the regions near $x = \pm 1$, therefore, the leading particle effects are much less pronounced. For both experiments studied, the center of mass longitudinal rapidity distributions are similar and have a Gaussian-like shape with peak value at about $y = 0.75$, which corresponds to an average longitudinal momentum of K^0 equal to about $\langle p_L \rangle = 0.530 \text{ GeV}/c$.

4.3. The distributions of K^0 -mesons in terms of the invariant variables t and M

The spectra of the missing mass to the K^0 are presented in fig. 4.9 together with the data from the $5 \text{ GeV}/c \text{ } K^+p$ experiment. In the low mass region structures may be observed which represent production of baryonic resonances. One notices the strong Δ^{++} peak for the K^+p interactions and much smaller ones for the Δ^0 and $N_{1/2}^0$ production in K^-p interactions. The one bin enhancement in the region of 950 MeV for the K^-p reactions gives an order of magnitude for the charge exchange reaction $K^-p \rightarrow \bar{K}^0 n$. However, for values of the effective mass M of the system X larger than about 2.0 GeV , the distributions become smooth and compatible with an exponential shape up to kinematic limit. This fact is surprising because the missing mass distributions represent the sum over all the distributions corresponding to final states of different multiplicities, which as can be seen in fig. 4.10 are neither similar to each other nor exponential. An interesting fact is that this exponential behaviour of the missing mass distributions remains also when one selects the events which have four-momentum transfer to K^0 $t' < 1.0 (\text{GeV}/c)^2$.

Table 4.2 summarises the results of fits to the missing mass distributions with the formula

$$\frac{d\sigma}{dM} = \sigma_0 e^{-kM} \quad (4.3.)$$

TABLE 4.2

Fitted coefficients in formula (4.3), $d\sigma/dM = \sigma_0 e^{kM}$

Reaction	Mass range (GeV)	t' range (GeV ²)	σ_0 ($\mu\text{b}/\text{GeV}$)	k (GeV ⁻¹)	$\chi^2/\text{degrees}$ of freedom
$K^+ p \rightarrow K^0 X^{++}$ at 5 GeV/c	2.0 - 2.5	All	40.6 ± 2.0	2.10 ± 0.05	21/8
		0 - 1.0	49.6 ± 2.4	1.81 ± 0.05	32/8
$K^+ p \rightarrow K^0 X^{++}$ at 8.2 GeV/c	2.0 - 3.45	All	17.1 ± 0.8	1.70 ± 0.05	47/27
		0 - 1.0	44.3 ± 2.1	1.33 ± 0.05	36/27
$K^- p \rightarrow \bar{K}^0 X^0$ at 10.1 GeV/c	2.0 - 3.8	All	19.1 ± 0.9	1.65 ± 0.05	42/34
		0 - 1.0	34.1 ± 1.7	1.31 ± 0.05	42/34

As can be seen, in all cases the exponential slope k decreases slowly with increasing energy. For events with $t' \lesssim 1.0 \text{ GeV}^2$ the values of the slope k are somewhat lower, but present the same behaviour as for the total samples.

As may be also observed in fig. 4.9, the cross section for a given band of mass M values decreases strongly with increasing incoming momentum, namely approximately as $p_{\text{LAB}}^{-2.5}$, thus showing similar behaviour to that observed for two-body charge-exchange reactions [12]. This may perhaps be an indication that the power dependence of the cross section on energy is more general and not restricted to the two-body and quasi-two-body processes.

The distributions of the four-momentum transfer t and $t' = |t - t_{\text{min}}|$ of K^0 s from $K^- p$ and $K^+ p$ experiments are shown in figs 4.11 and 4.12. In both cases the general behaviour of these distributions is similar for K^- and K^+ incident particles. Furthermore, the same is true for the t' distributions for the different fixed mass bands of the system X produced together with K^0 , presented in fig. 4.13.

In all cases the distributions are well described by an exponential function for the values of $t' \lesssim 1.0 \text{ (GeV/c)}^2$. The fits of the t' distributions with the formula

$$\left(\frac{d\sigma}{dt'} \right)_{M=\text{const}} = (\text{const}) \cdot e^{-At'} \quad (4.4)$$

were performed in each mass interval of 100 MeV.

The fitted values of the slope parameter A as a function of the missing mass, M , are presented in figs 4.14a) and b) for K^-p and K^+p experiments, respectively.

Since, as was also concluded from the study of other distributions, there is no significant difference between the distributions of K^0 s produced in K^+p and K^-p interactions, we have combined the data from both experiments and repeated the fitting of the formula (4.4). The resulting slopes are presented in fig. 4.14c). The well known fact that the exponential slope A decreases with increasing mass [13] is clearly visible. The mass dependence of the slope A was fitted with the formula

$$A = c \left(\frac{M}{M_0} \right)^{-\alpha} \quad (4.5)$$

where $M_0 = 1.0 \text{ GeV}$, and the values $c = 26.4 \pm 2.5 \text{ GeV}^{-2}$ and $\alpha = 2.34 \pm 0.12$ were obtained.

It is always of interest to find simple rules governing regularities in the features of hadron collisions, e.g. description of the distributions by simple functions. In particular, as will be shown in sect. 6 the fits to the one-dimensional distributions may be sometimes used in constructing fully-differential parameterizations of the data.

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FIGURE CAPTIONS

- 4.1 Double differential cross section distributions
 $d^2\sigma/dp_{\text{LAB}} d\Omega_{\text{LAB}}$ for K^0 mesons produced in K^+p interactions at 8.2 GeV/c and K^-p at 10.1 GeV/c.
- 4.2 K^0 laboratory momentum distributions for K^+ and K^- interactions.
- 4.3 K^0 longitudinal momentum distributions in the mirror system for K^+p interactions at 5 and 8.2 GeV/c and K^-p at 10.1 GeV/c.
- 4.4 Transverse momentum squared distribution of K^0 .
- 4.5 Average transverse momentum of K^0 as function of its longitudinal momentum, unweighted (a and c) and weighted (b and d) for K^+p interactions at 8.2 GeV/c and K^-p interactions at 10.1 GeV/c
- 4.6 Distribution of $d\sigma/dx$ for K^0 , where $x = P_L^*/P_{L\text{MAX}}^*$.
- 4.7 The invariant E^* . $d\sigma/dx$ distributions of K^0 at different incoming momenta.
- 4.8 Longitudinal rapidity distributions of K^0 for K^-p and K^+p experiments.
- 4.9 Effective mass spectrum $d\sigma/dM$ of the system X.
The solid lines represent the fits to the data with eq. (4.3).
- 4.10 Missing mass distributions $d\sigma/dM$ for different multiplicities in the final state.
- 4.11 Distribution of the squared four-momentum transfer t from incident kaon to produced K^0 .
- 4.12 The $t' = |t - t_{\text{min}}|$ distributions of K^0 .
- 4.13 The $t' = |t - t_{\text{min}}|$ distributions of K^0 for different mass bands of the system X.
- 4.14 Slope parameter A from eq (4.4) as the function of the effective mass M.
 - a) for the reaction $K^-p \rightarrow \bar{K}^0 X^0$ at 10.1 GeV/c
 - b) for the reaction $K^+p \rightarrow K^0 X^{++}$ at 8.2 GeV/c
 - c) for the sum of both experiment.The solid line is the fit with the formula (4.5).

Fig. 4.1

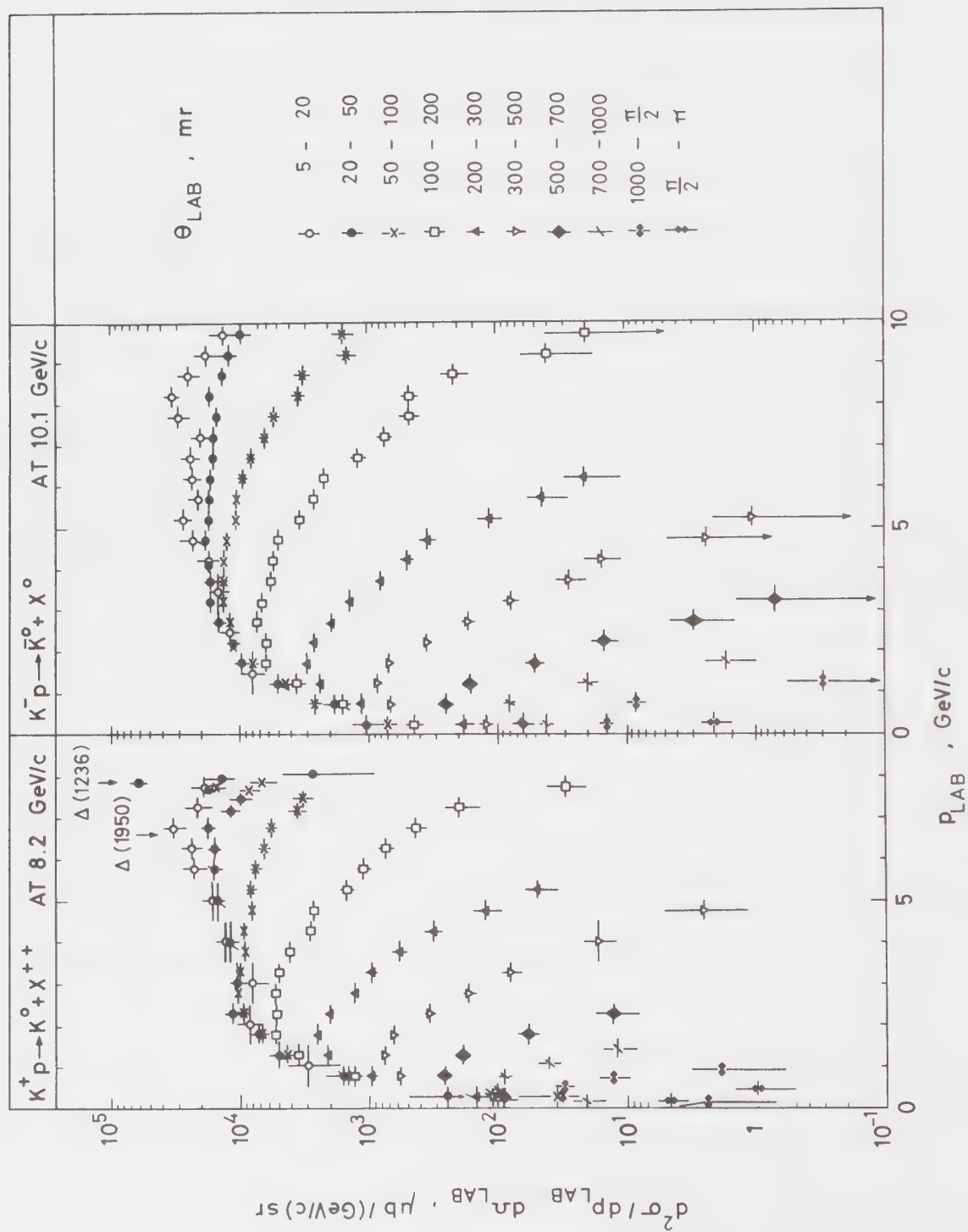


Fig. 4.2

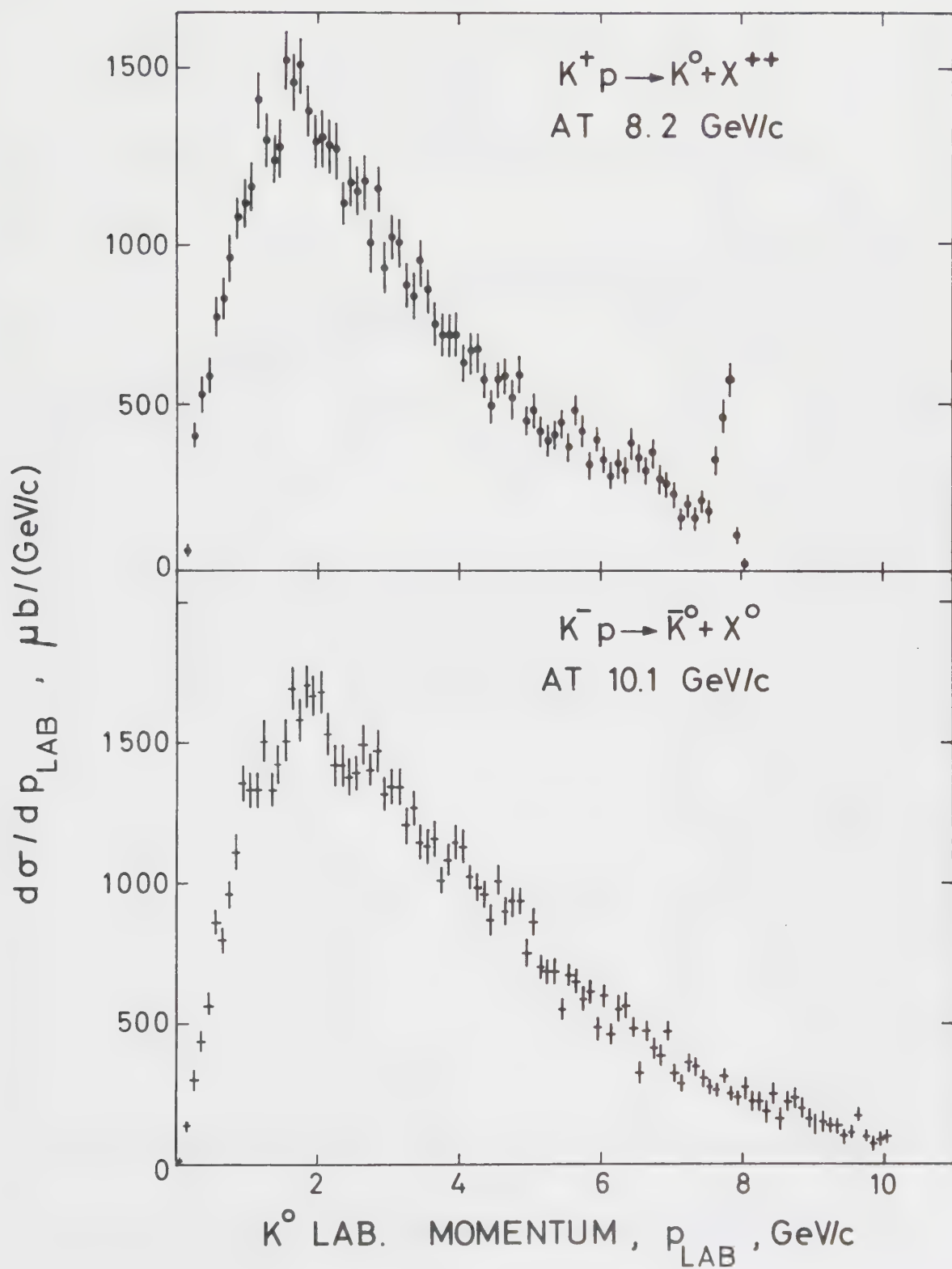


Fig. 4.3

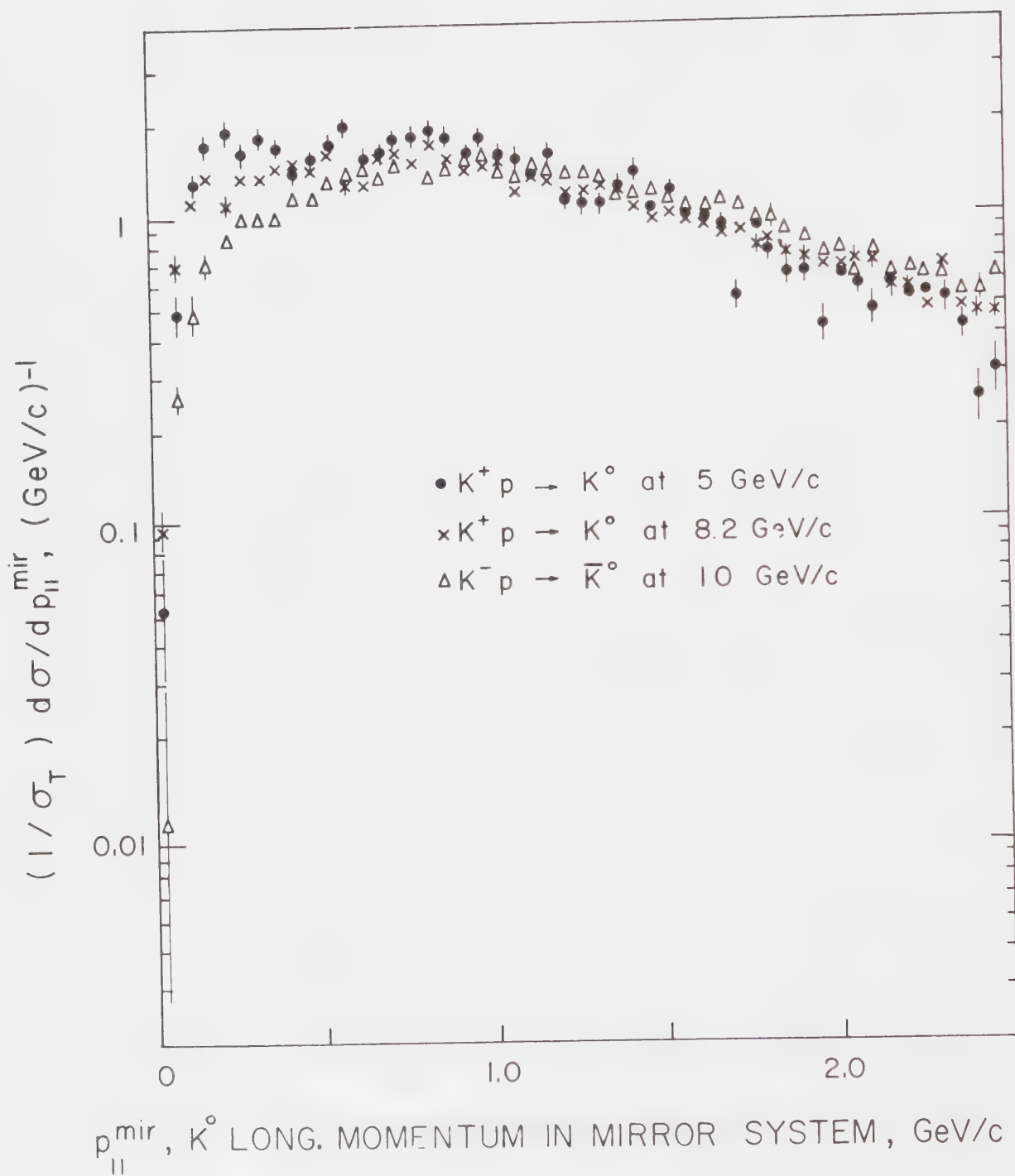


Fig. 4.4

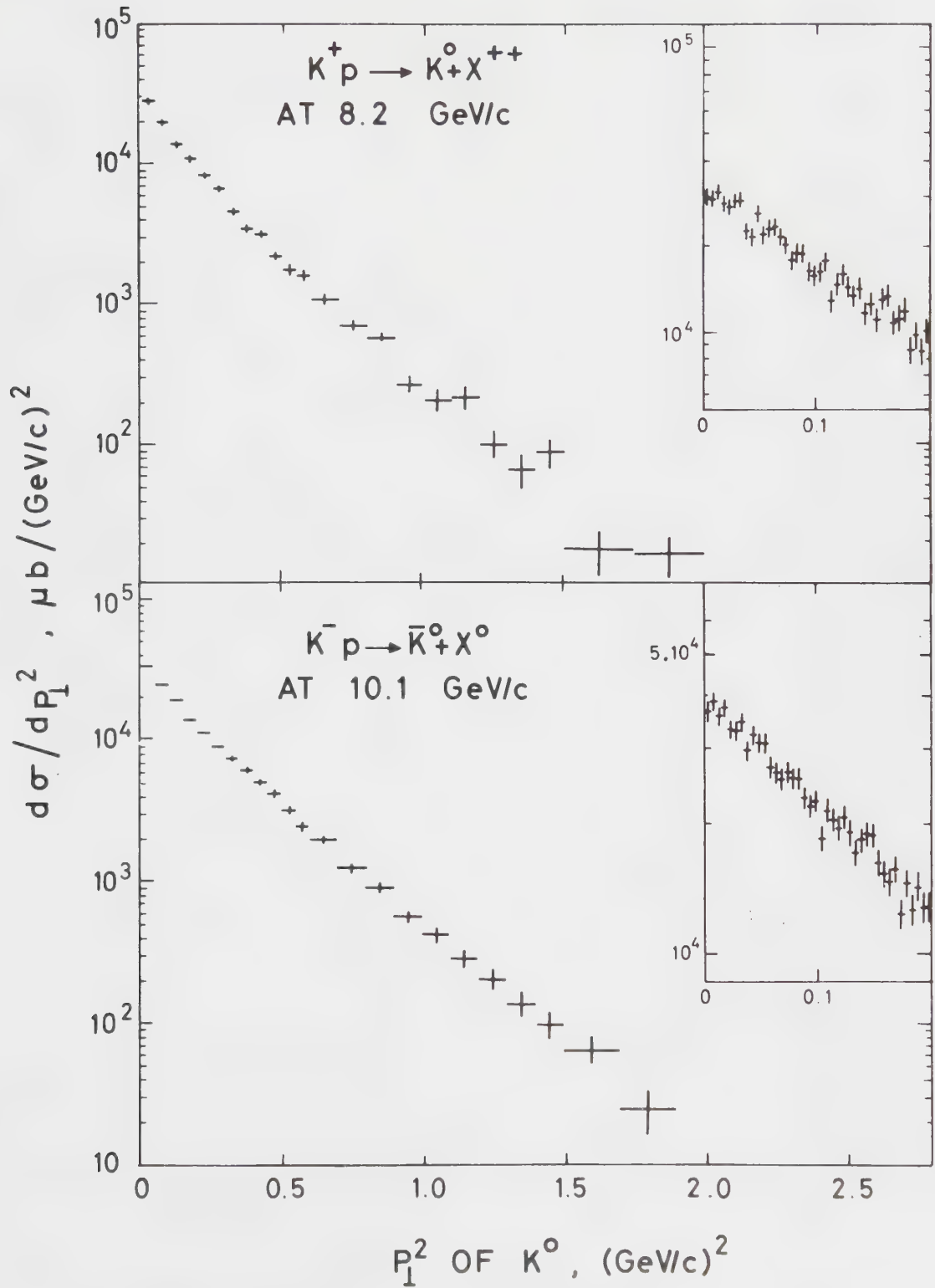


Fig. 4.5

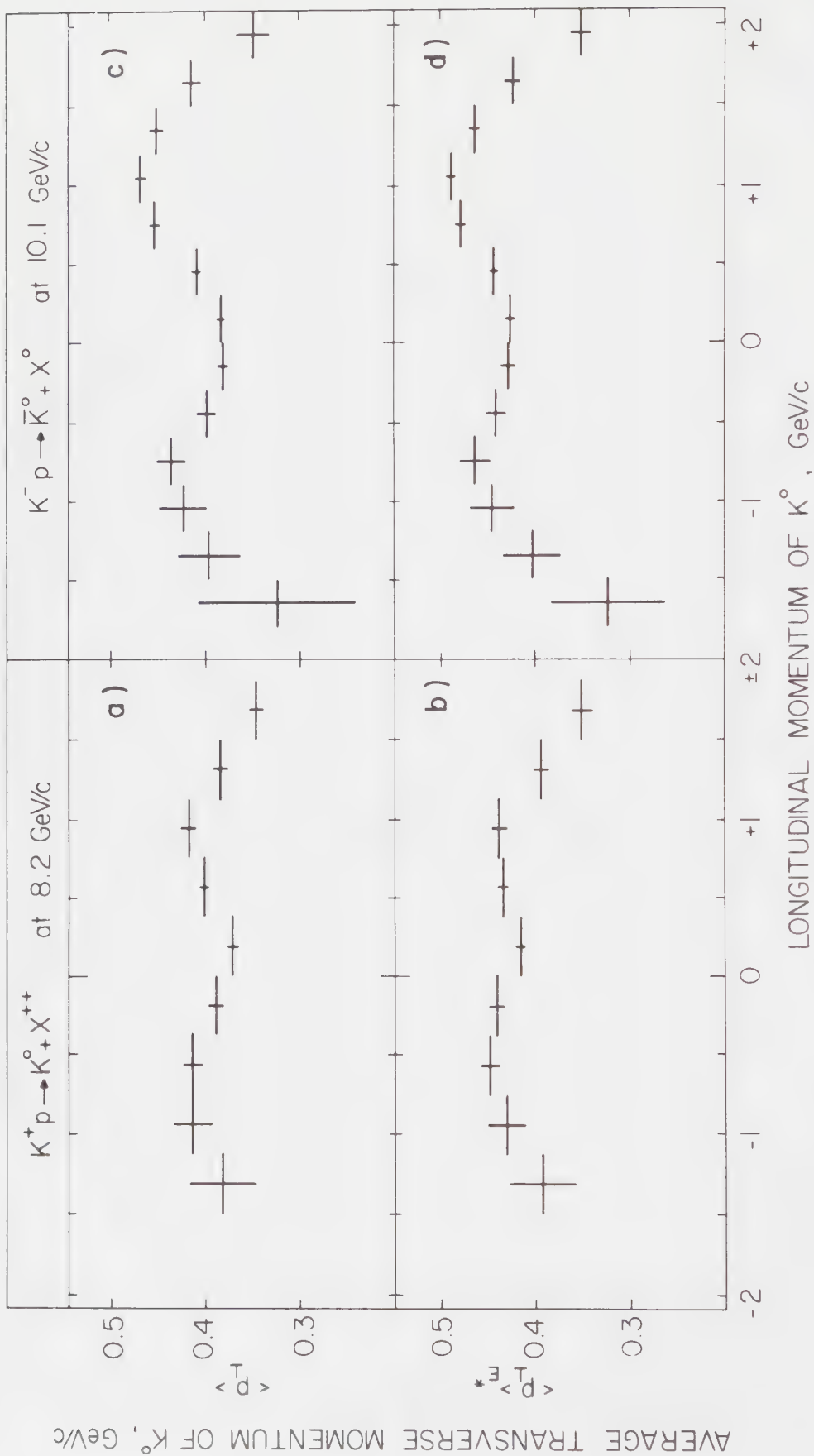


Fig. 4.6

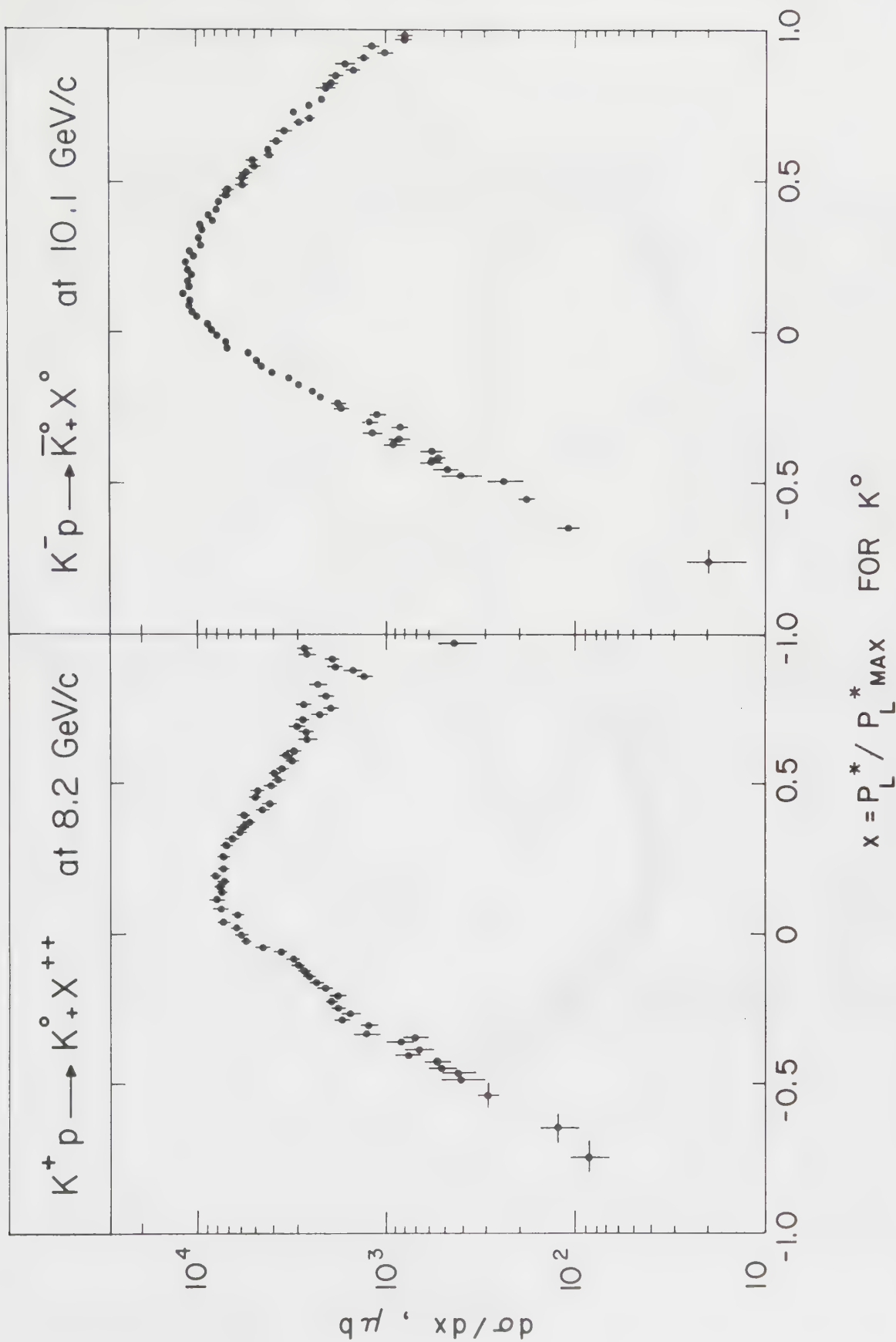
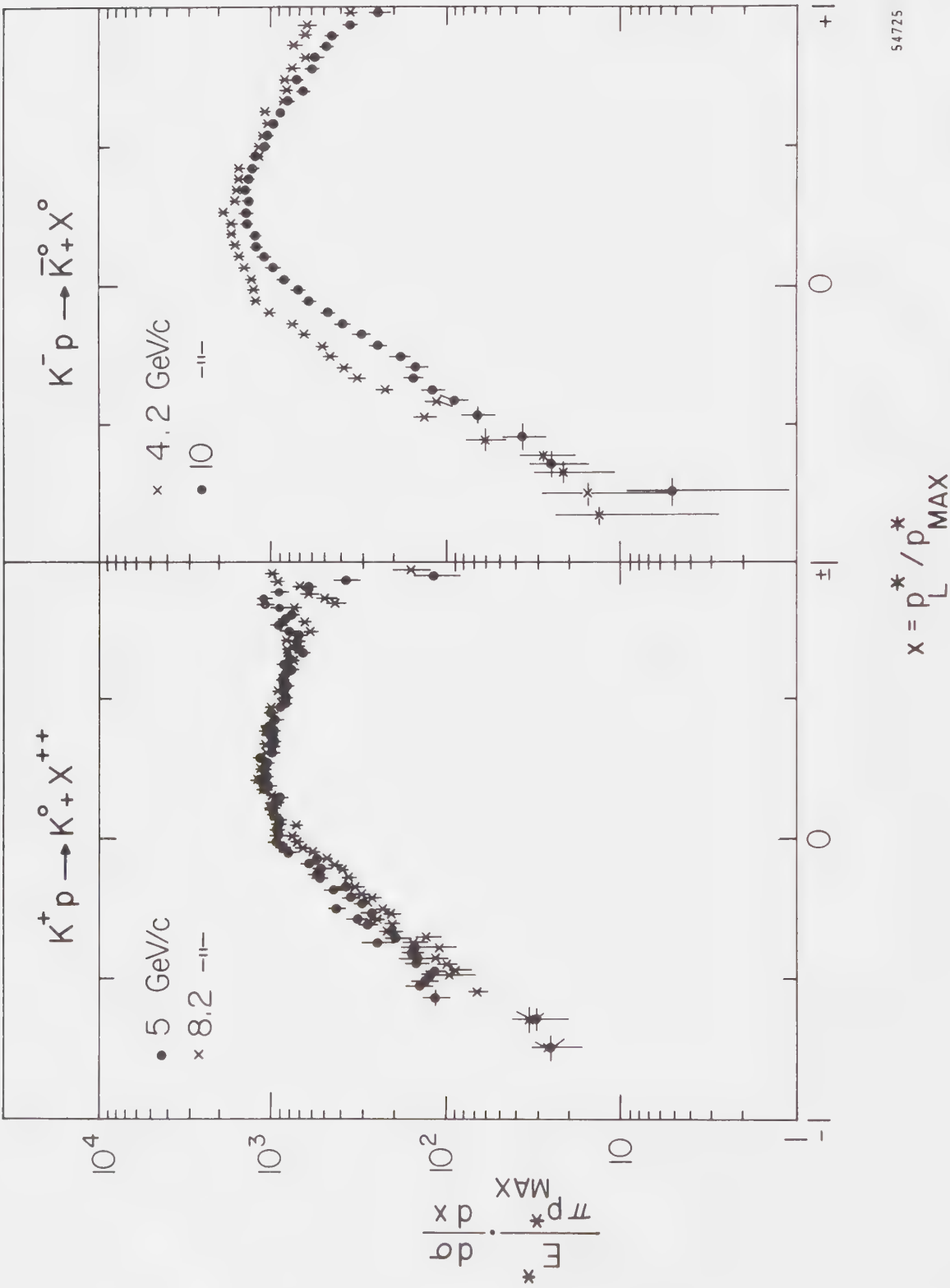


Fig. 4.7



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Fig. 4.10

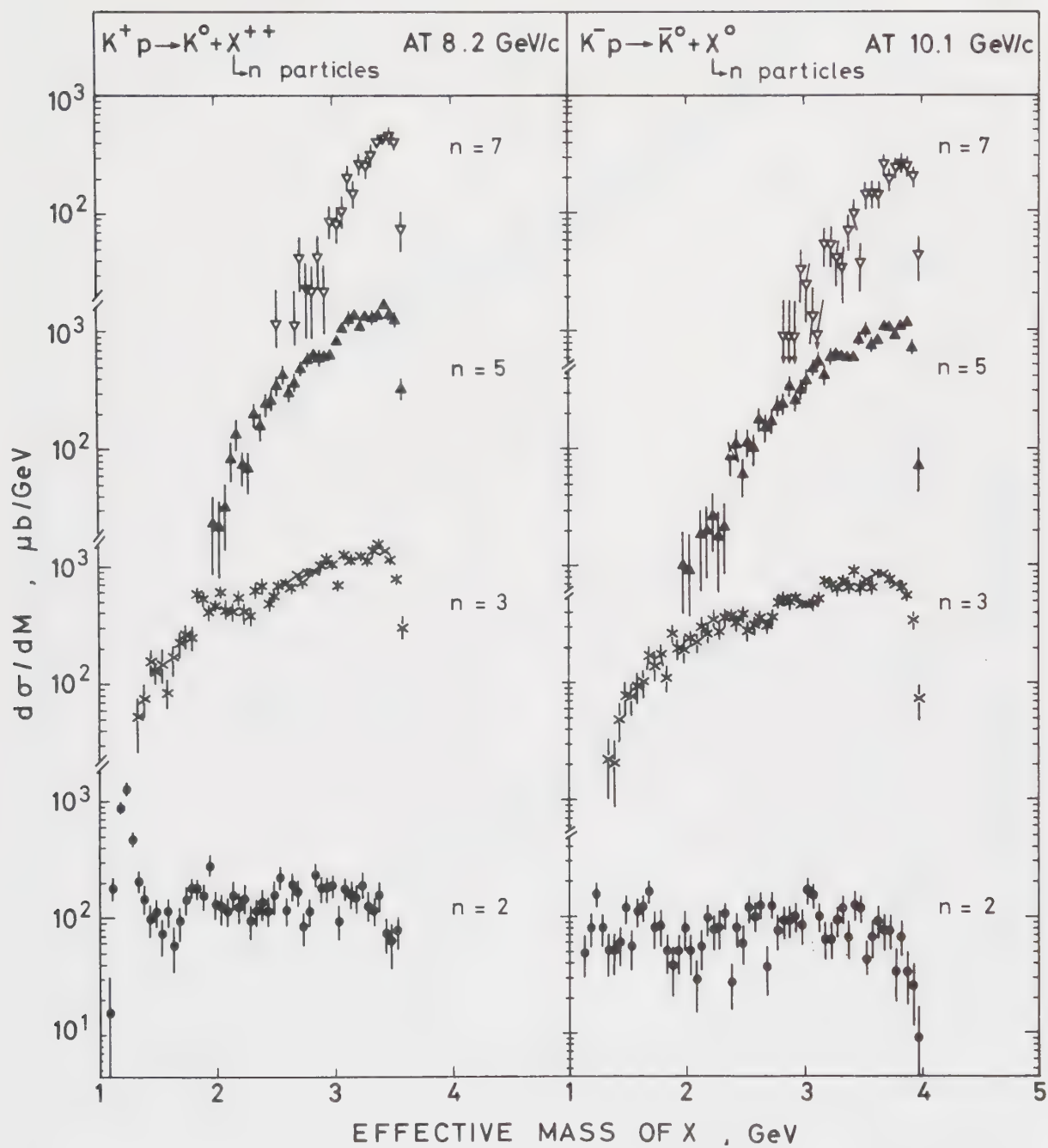


Fig. 4. II

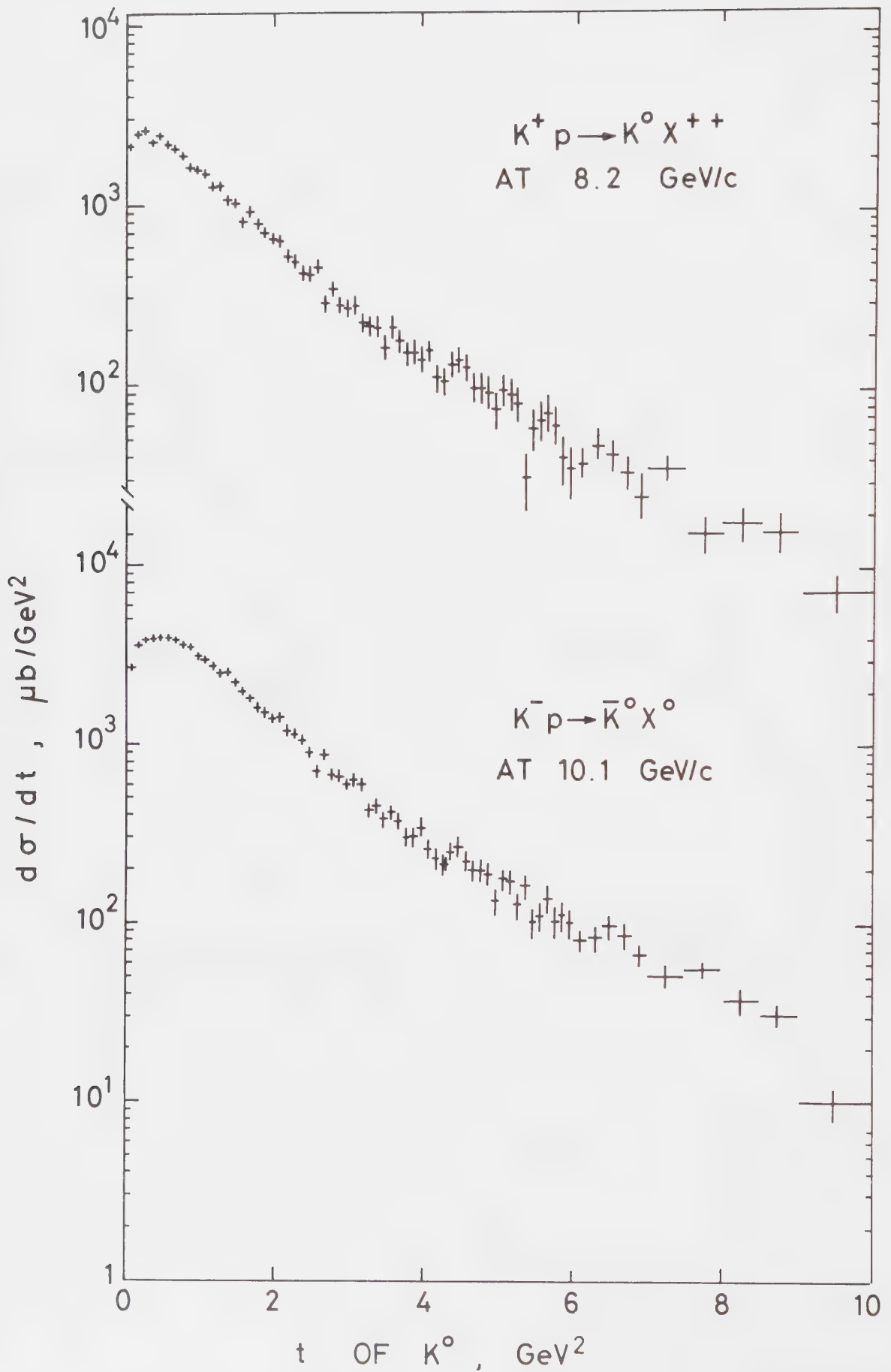


Fig. 4.10

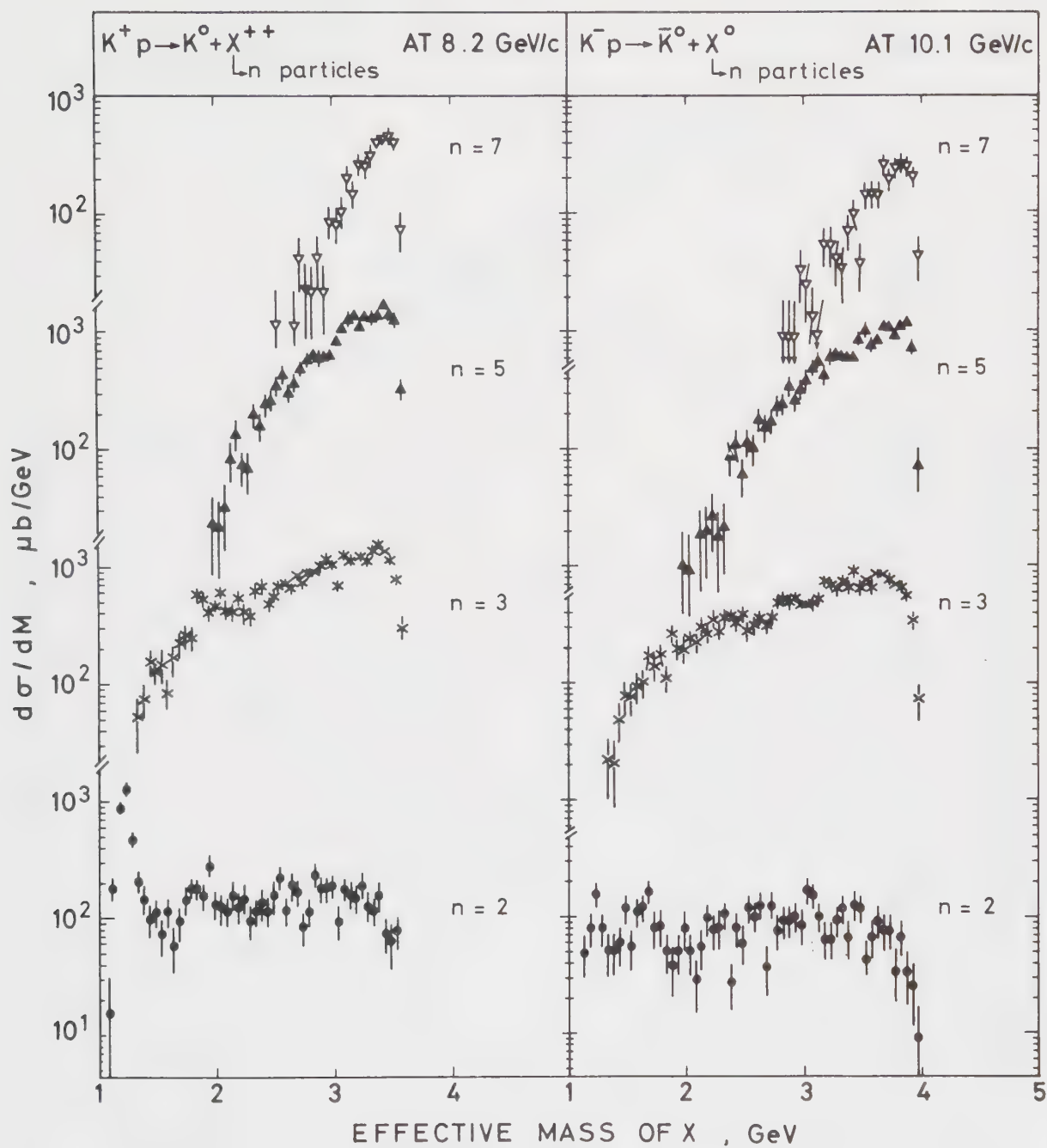


Fig. 4. II

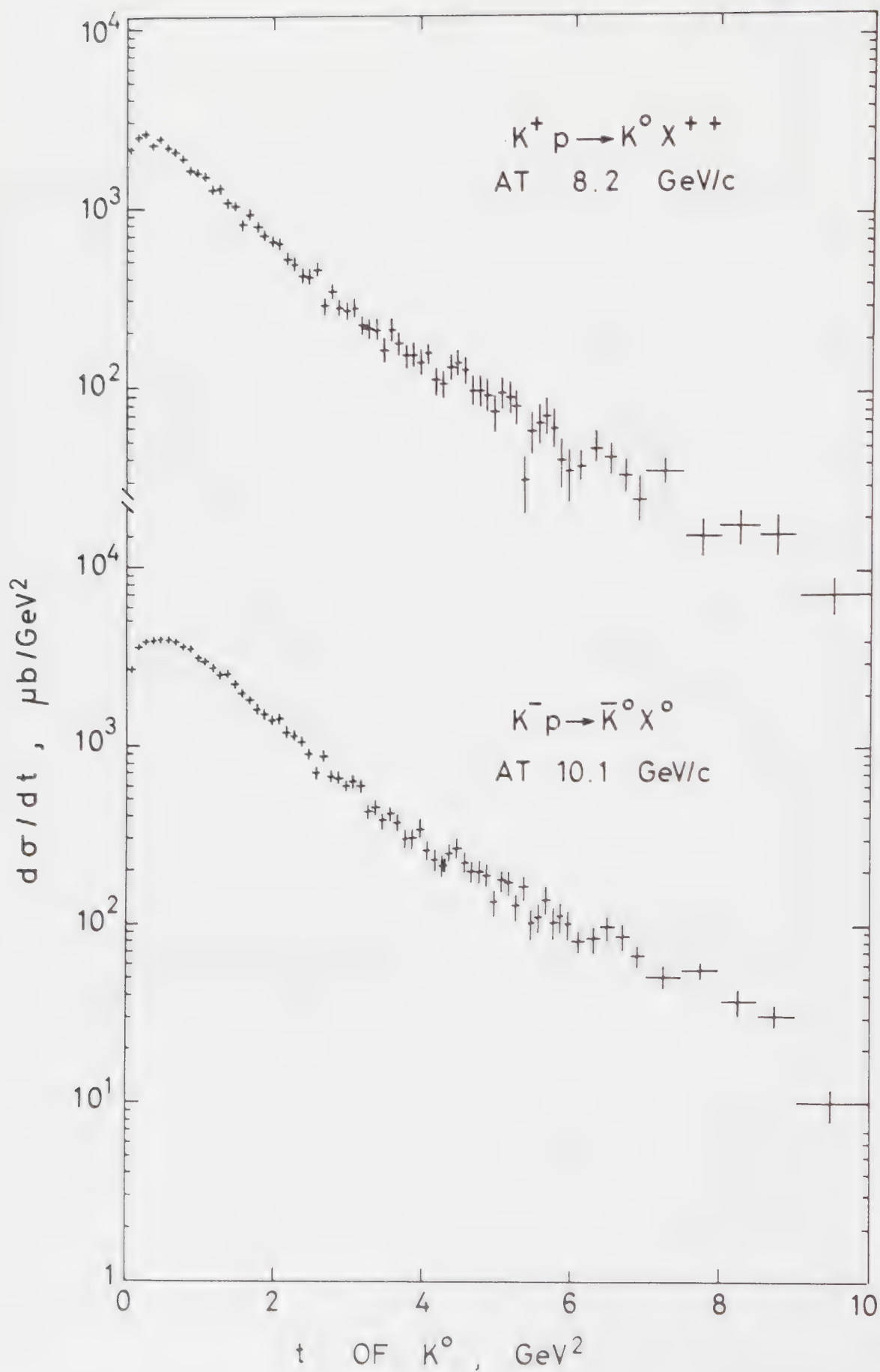


Fig. 4.12

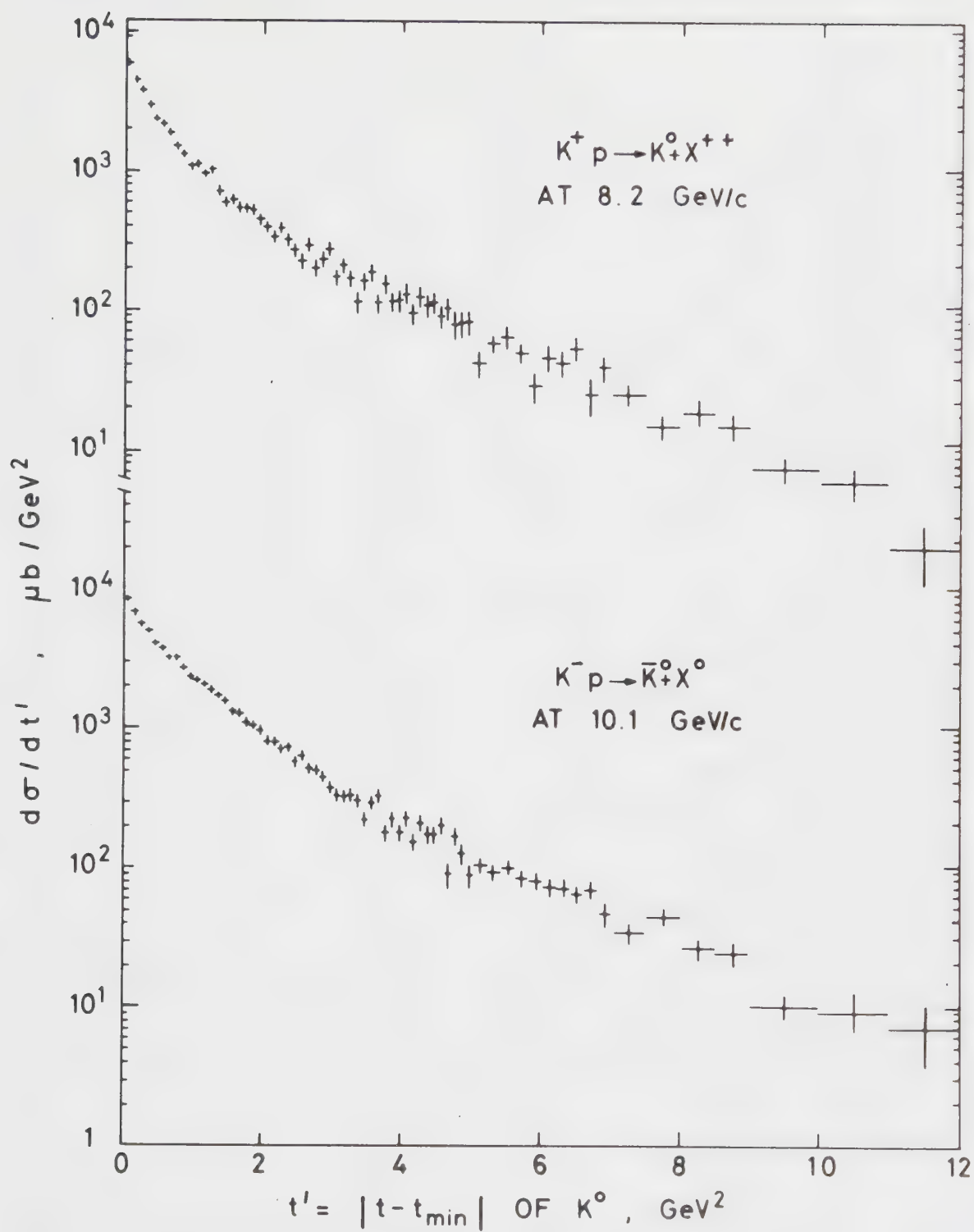


Fig. 4.13

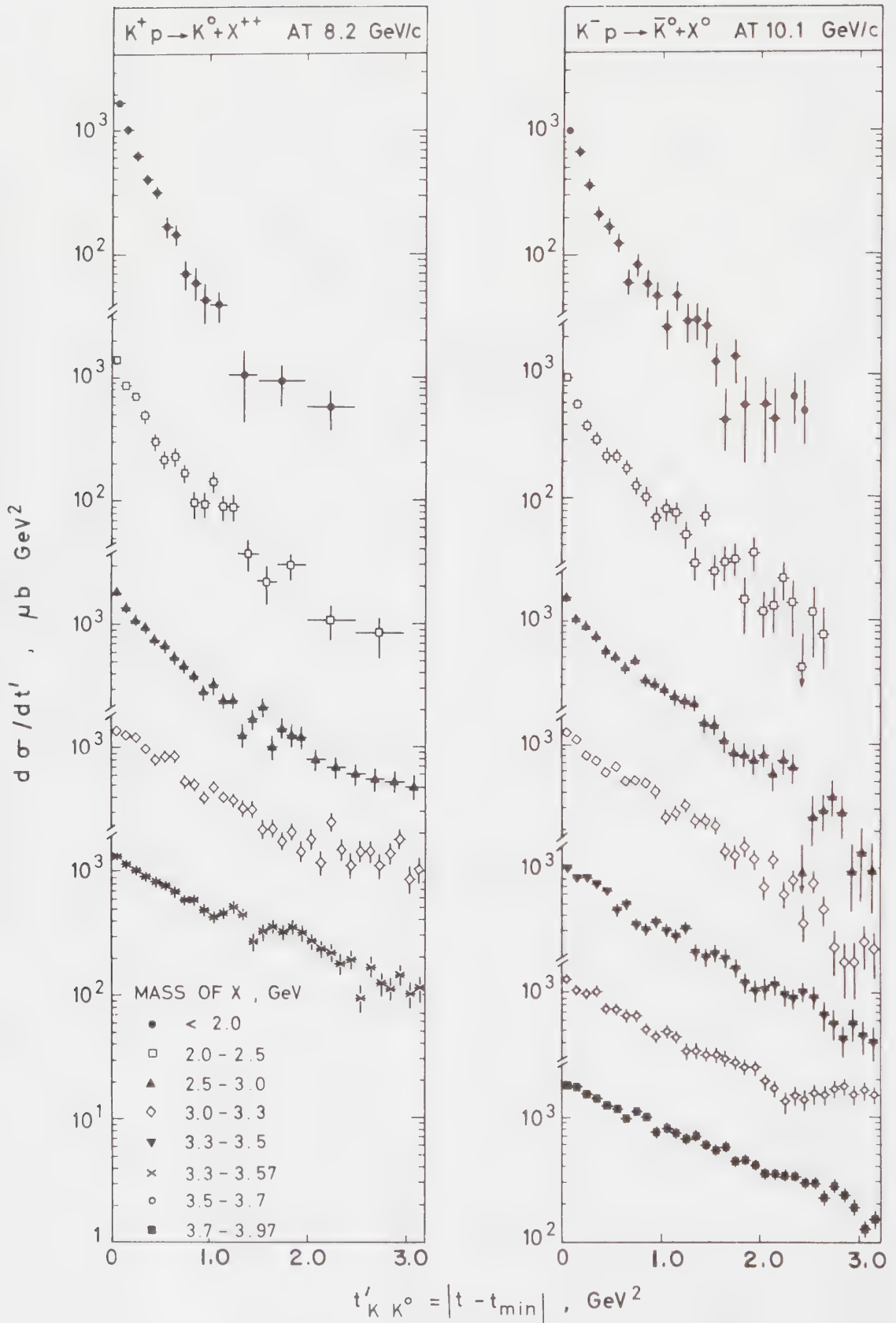
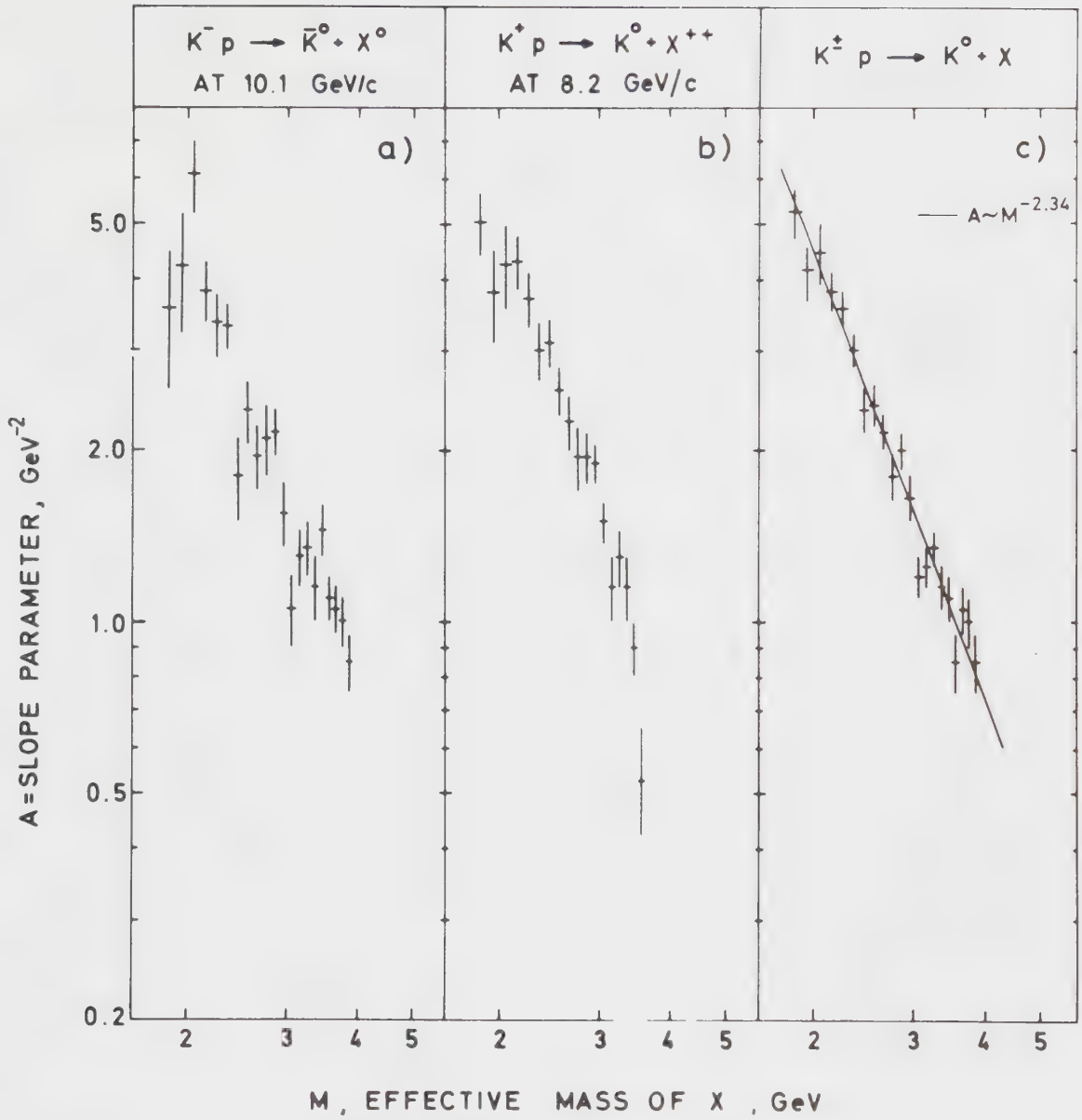


Fig. 4.14



5. COMPARISON OF THE EXPERIMENTAL DATA WITH PHASE-SPACE PREDICTIONS

The phase-space element represent the probability of observing a particle in the volume d^3p around p in the momentum space under assumption that all the states conserving energy-momentum are equally probable. In the relativistic case, the element of the Lorentz Invariant Phase Space (LIPS) is given by $[1,2]$

$$dLIPS = \frac{1}{(2\pi)^3} \frac{d^3p}{2E} = \frac{d^4p}{(2\pi)^3} \delta(p^2 - m^2),$$

where E denotes the energy of the particle of the mass m . For a system containing n particles of masses m_i , their four-vectors p_i and the total four-vector of the system P

$$dLIPS(p_1, \dots, p_n) = (2\pi)^{-3n} \prod_{i=1}^n \frac{d^3p_i}{2E_i}$$

and thus the n -body phase-space integral R_n is defined as :

$$R_n = (2\pi)^{3n} \int dLIPS = \int \delta^4(P - \sum_{j=1}^n p_j) \prod_{i=1}^n \delta(p_i^2 - m_i^2) d^4p_i$$

This integral follows from the statistical theory introduced by Fermi $[3]$ based on statistical thermodynamics and gives the density of states in momentum space. Moreover, it includes the kinematic factor expressed by the delta functions, which takes into account energy and momentum conservation.

In general, the distribution of any parameter α of the system with n particles in the final state is given by

$$f(\alpha) = \frac{d}{d\alpha} \int |M|^2 dLIPS,$$

where M is the matrix element describing the dynamical part of the interaction. In particular, if one is interested in the distributions following from the kinematics of the interaction only, one may take

$|M| = 1$ and

$$f(\alpha) = \frac{d}{d\alpha} R_n$$

The integral R_n can be solved analytically (apart from few special cases) only for $M = 1$ and $n = 1, 2$ and 3 . The most efficient method used for practical purposes at higher multiplicity is the Monte-Carlo generation method.

In order to study in more detail the distributions presented in section 4 and the effects coming from the pure kinematics, we have calculated the phase-space predictions for these distributions for the 10 GeV/c K^-p experiment using the Monte-Carlo generating program FOWL [4]. We have calculated these predictions for systems consisting of nucleon, kaon and n pions, where n ranged from 0 to 8. In order to obtain the inclusive distributions we had to introduce additional assumption, that the relative probabilities of observing the states, with particles of different charges in the same multiplicity channels are given by the statistical isospin weights. In other words the distributions for different multiplicities were added together using as weights the cross sections for a given multiplicity as calculated in section 3. In figs. 5.1 - 5.5 the experimental data are compared with the corresponding phase-space predictions after normalisation to the same inclusive cross section. One can see that except for the MM distribution, phase-space does not describe the data. This is mainly due to two fundamental dynamical effects not taken into account in calculations, namely, the existence of leading particles and the limitation of transverse momenta. It is most interesting, that in spite of the neglect of those dynamical factors, the missing mass distribution presented in fig. 5.3 is very well described by phase-space apart from the small mass region of resonance production. It is interesting also to note that for the x distribution of K^0 -mesons the shape of the phase-space curve is very similar to the experimental shape for the negative

values of x , which correspond to backwards K^0 emission. The positive x values are dominated by the leading particles effect and are badly described by the phase-space curve.

In figs 5.6 - 5.8 the relative contributions to the total p_{LAB} , x and $p_{\perp}^2$ phase-space curves coming from various multiplicity channels are presented with appropriate weights. Here are clearly visible the facts described in section 4, namely, that the higher multiplicity events contribute mainly to the central region of the longitudinal momentum distribution. The phase-space distributions of transverse momentum squared for given multiplicities may be approximated roughly by the exponential functions in much larger range than for the inclusive sum with the slopes increasing with increasing multiplicity.

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FIGURE CAPTIONS

- 5.1. Comparison of the experimental laboratory momentum p_{LAB} distribution of $\bar{K}^0$ -mesons produced in the reaction $K^- p \rightarrow \bar{K}^0 + X^0$ at 10.1 GeV/c with the phase-space prediction.
- 5.2. Comparison of the experimental four-momentum transfer t' distribution of $\bar{K}^0$ -mesons produced in the reaction $K^- p \rightarrow \bar{K}^0 + X^0$ at 10.1 GeV/c with the phase-space prediction.
- 5.3. Comparison of the experimental missing mass to K^0 distribution in the reaction $K^- p \rightarrow \bar{K}^0 + X^0$ at 10.1 GeV/c with the phase-space prediction.
- 5.4. Comparison of the experimental reduced longitudinal momentum x distribution in the reaction $K^- p \rightarrow \bar{K}^0 + X^0$ at 10.1 GeV/c with the phase-space prediction.
- 5.5. Comparison of the experimental transverse momentum squared distribution in the reaction $K^- p \rightarrow \bar{K}^0 + X^0$ at 10.1 GeV/c with the phase-space prediction.
- 5.6 Contributions to the total phase-space curve for the laboratory momentum distribution of $\bar{K}^0$ mesons coming from various multiplicity channels.
- 5.7 Contributions to the total phase-space curve for the reduced longitudinal momentum distribution of $\bar{K}^0$ mesons coming from various multiplicity channels.
- 5.8 Contribution to the total phase-space curve for the transverse squared distribution of $\bar{K}^0$ mesons coming from various multiplicity channels.

Fig. 5.1

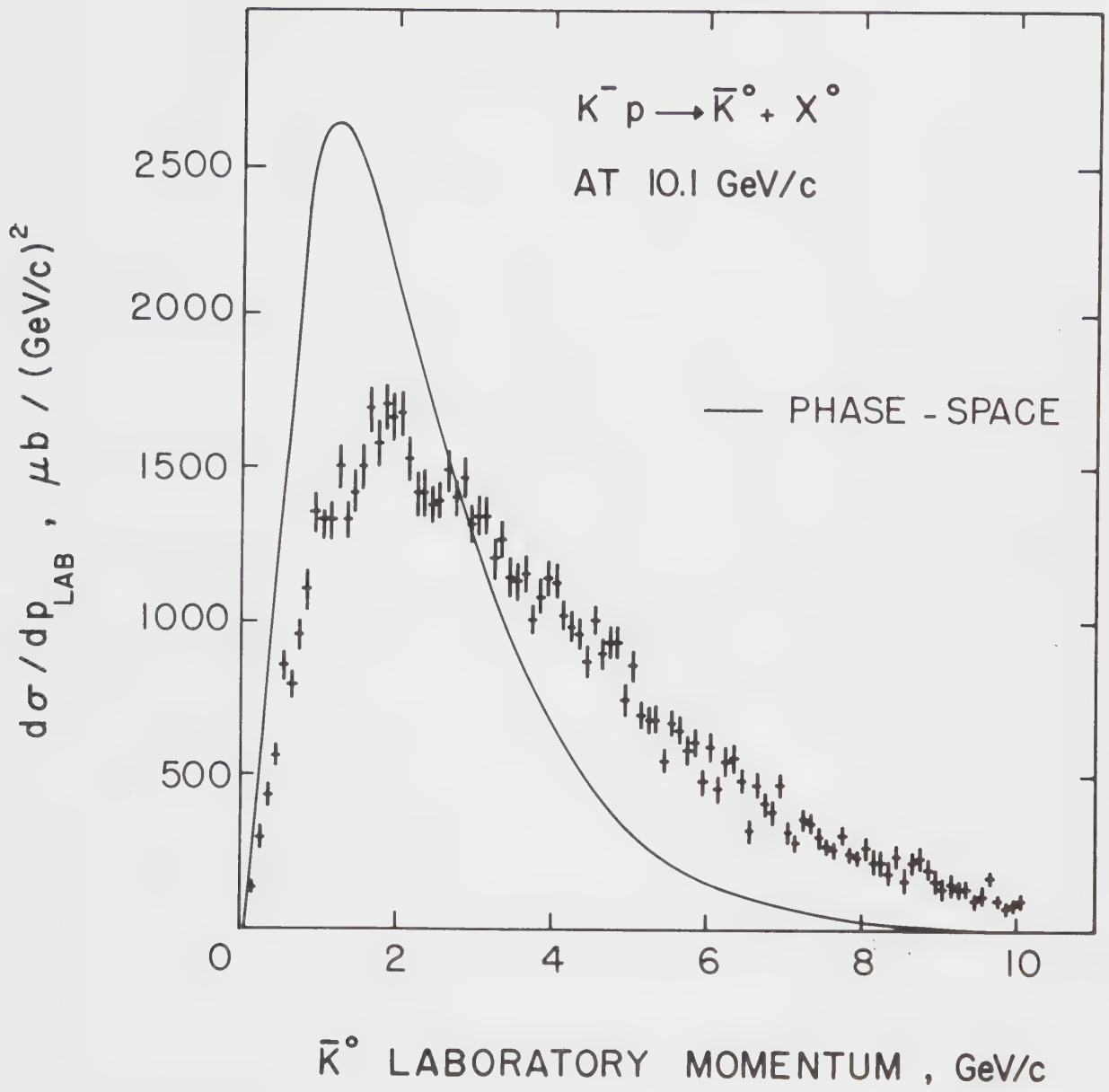


Fig. 5.2

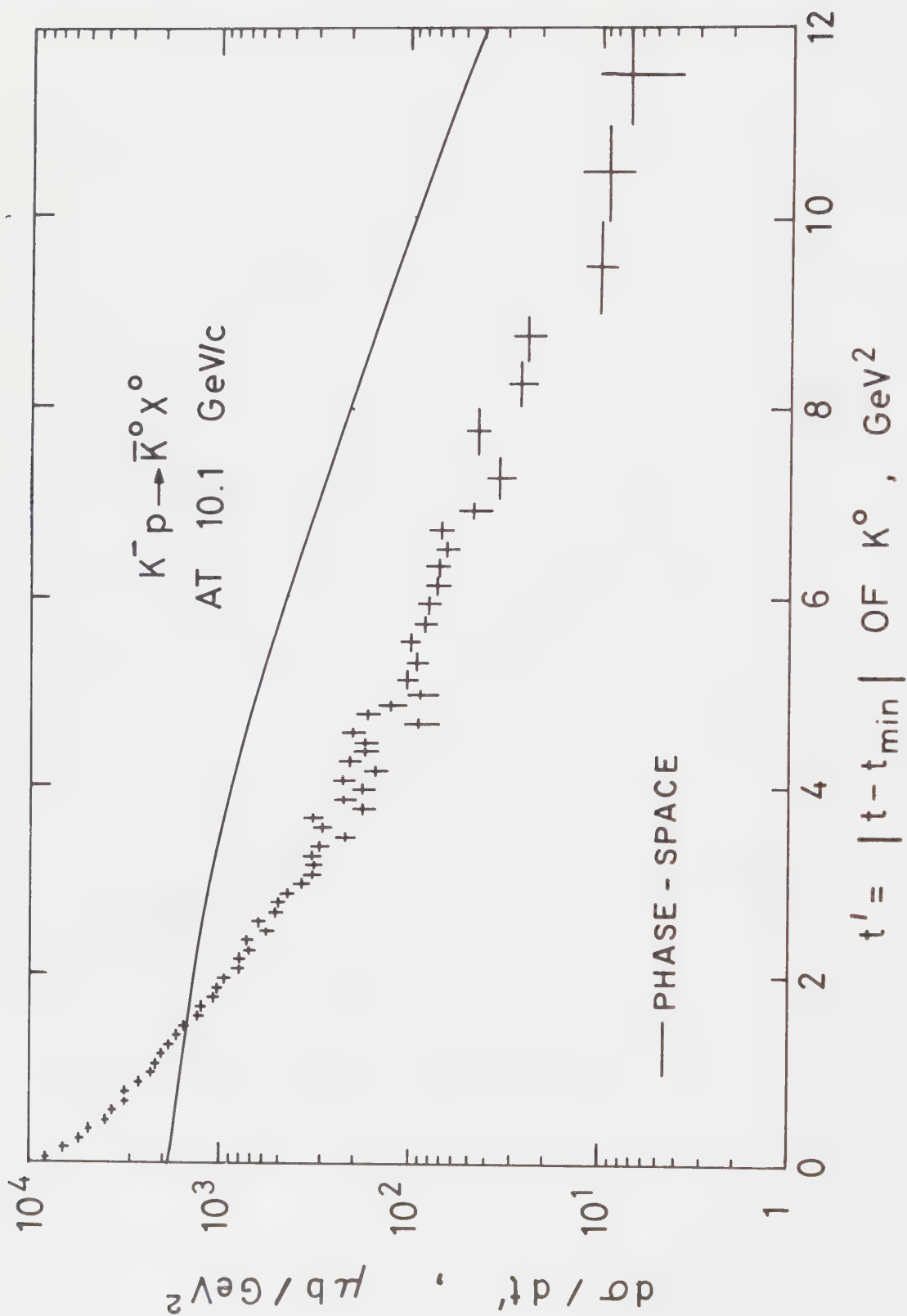


Fig. 5.3

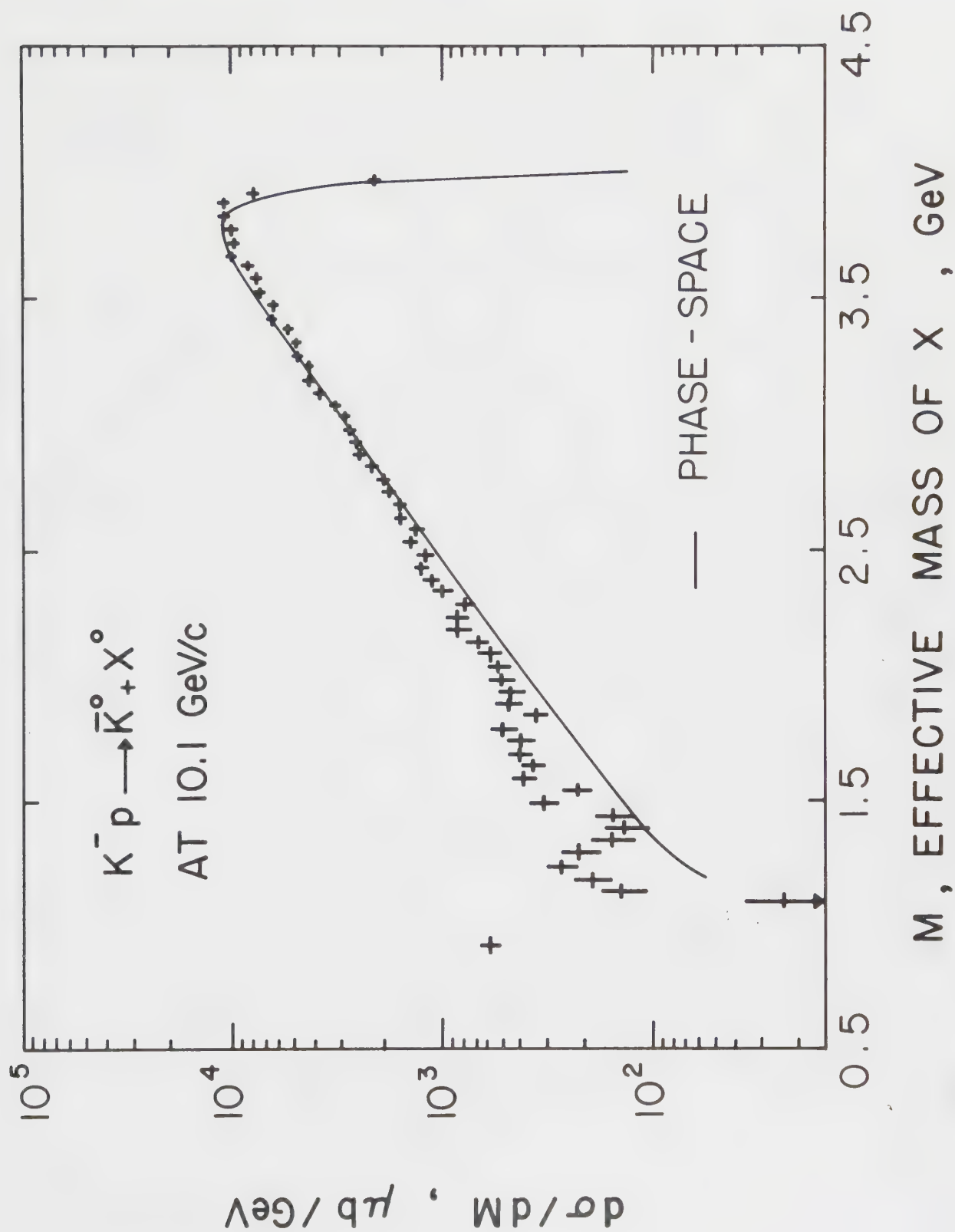


Fig. 5.4

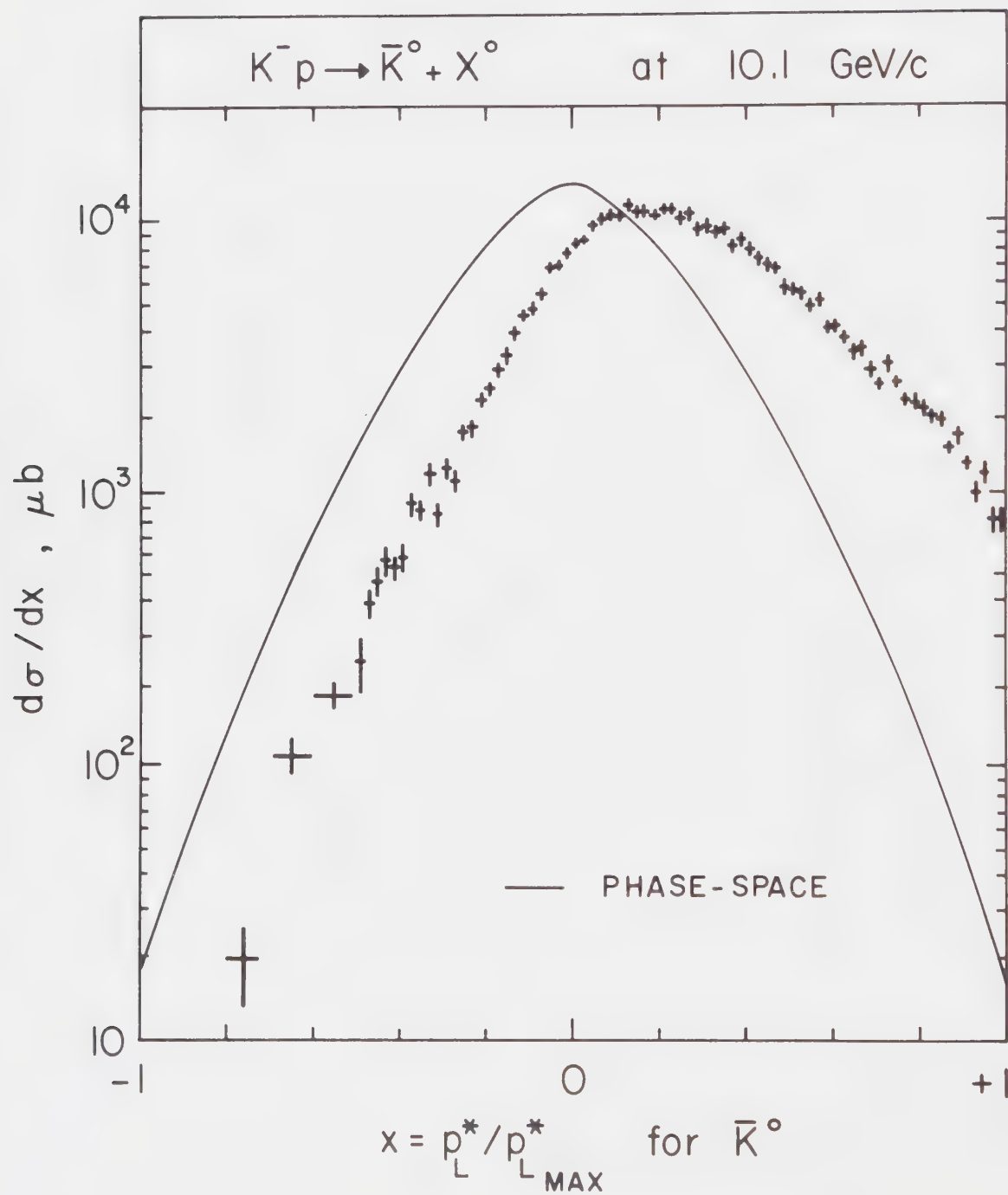


Fig. 5.5

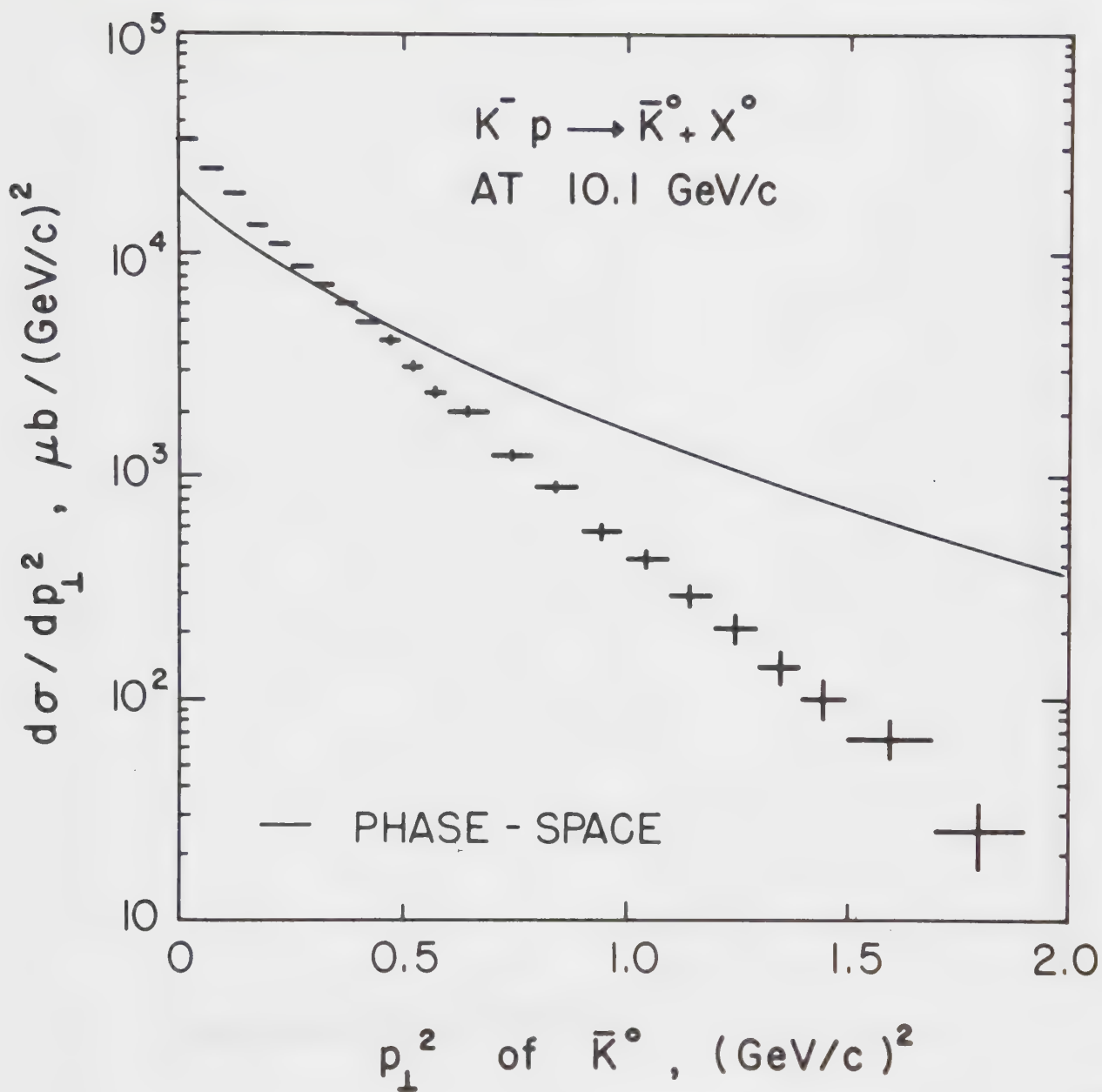


Fig. 5.6

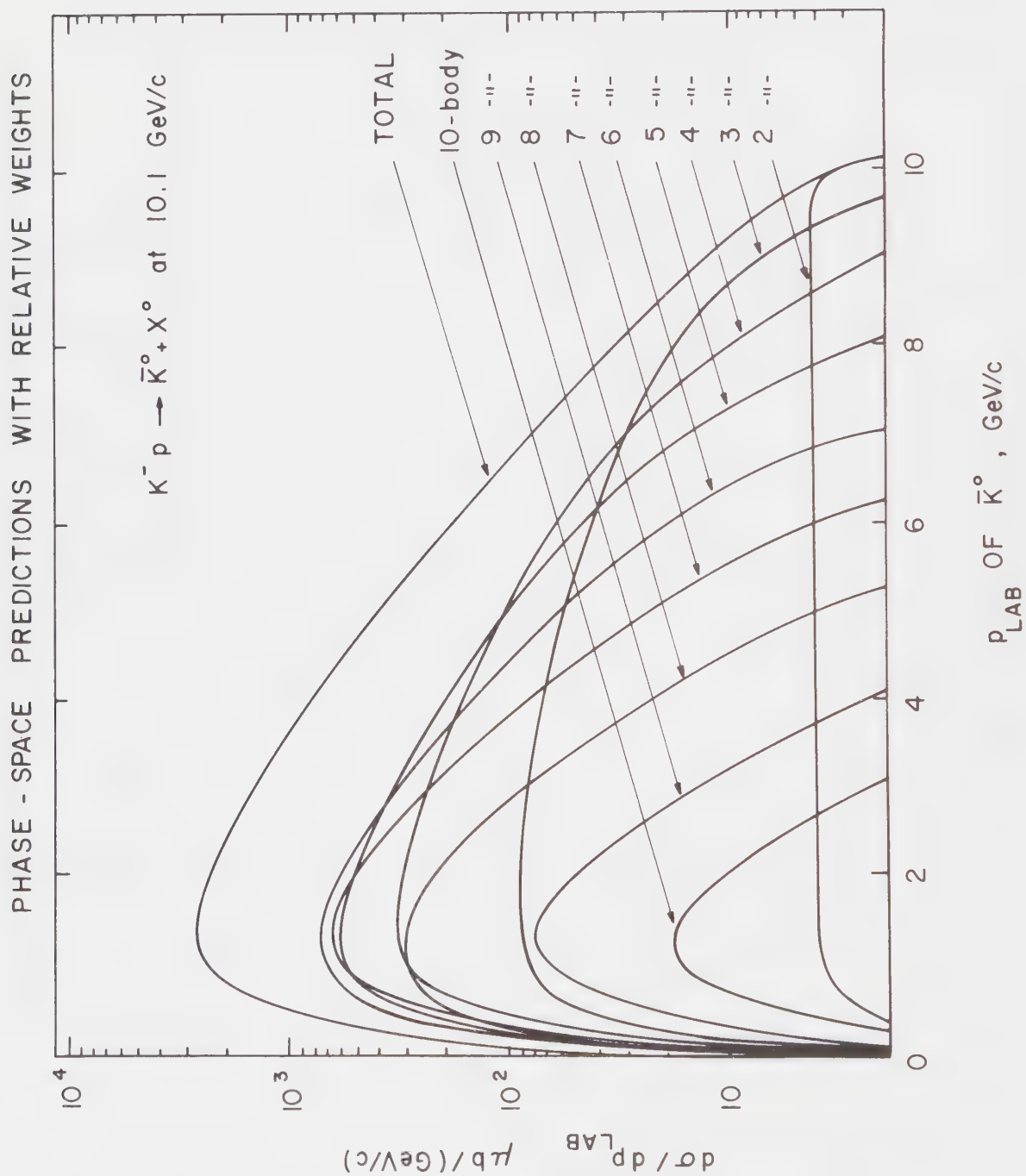


Fig. 5.7

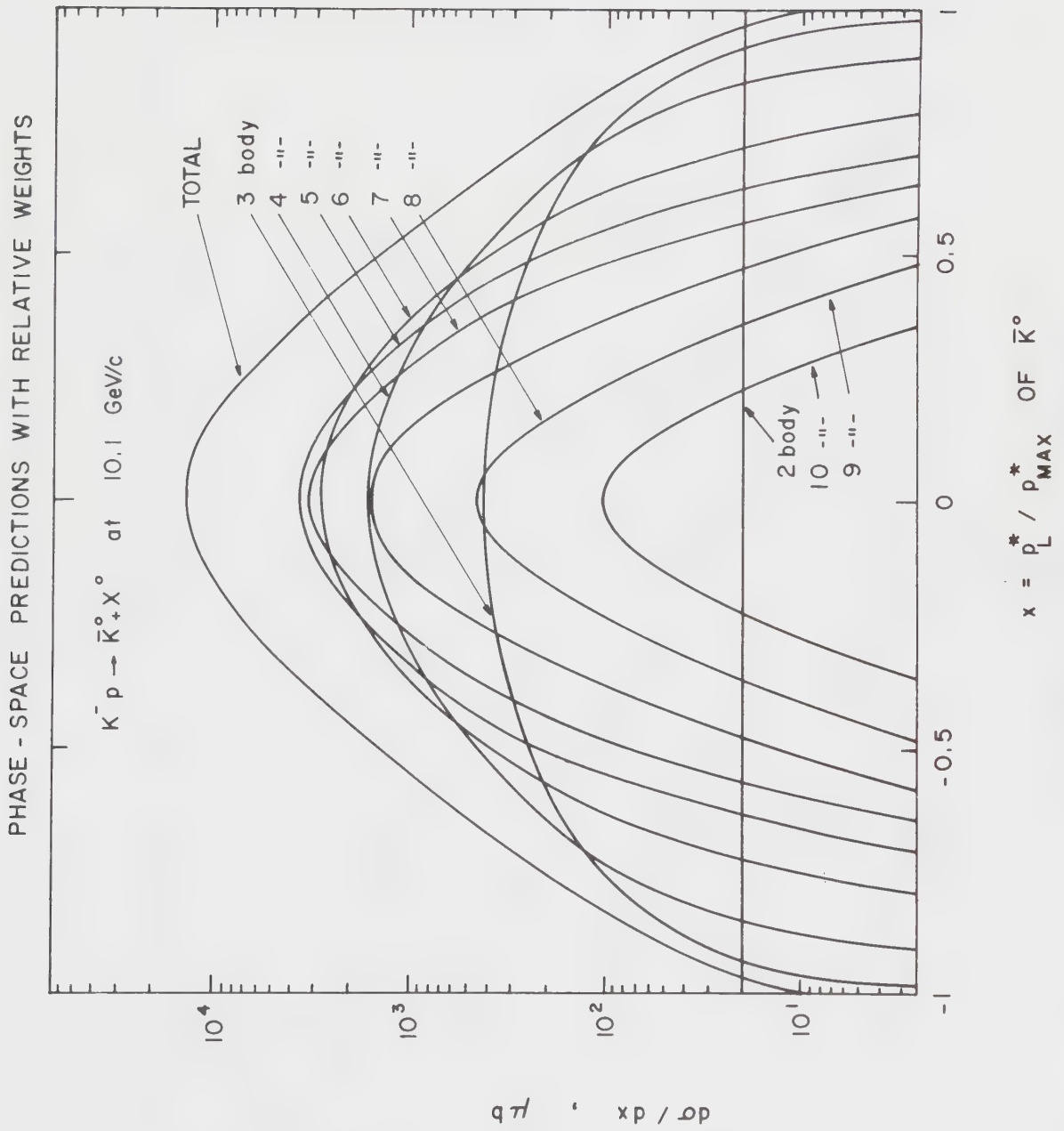
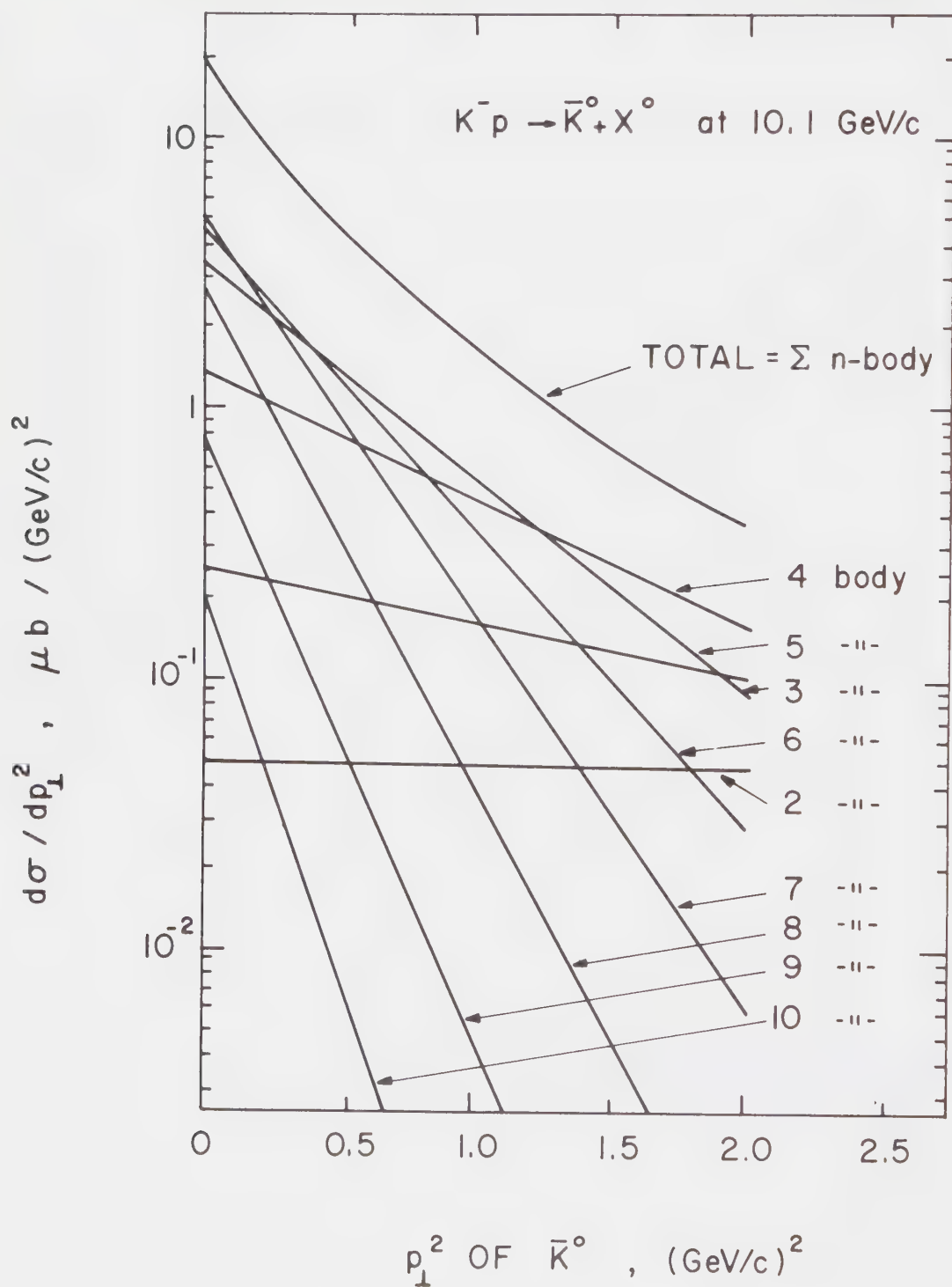


Fig. 5.8

PHASE-SPACE PREDICTIONS WITH RELATIVE WEIGHTS



6. PARAMETERISATION OF THE DIFFERENTIAL CROSS SECTION

After performing an experiment, the results of which are usually stored on the Data Summary Tapes in form of four-momentum vectors of particles, the experimentalists try to present the results in the form of the many one- and two- dimensional distributions which are of current interest. Unfortunately, it is not possible to foresee and present all the plots, which may be of importance for some particular theories and also preparation of such graphs involves usually much work and computer time.

It is, therefore, of great interest to find regularities of the distributions and to be able to describe them in the most compact form. In particular the differential form (e.g. the two- dimensional parameterisations of the single particle distributions at fixed energy) are very useful, since one can translate them to any other set of variables by simple Jacobian transformation.

In section 4.3. it was shown that at fixed energy the four-momentum transfer distributions of K^0 are approximately exponential in shape in every narrow band of the missing mass M , and that the exponential slope is strongly mass dependent.

$$\left(\frac{d\sigma}{dt'} \right)_M \approx \text{const} = (\text{const}) \cdot \exp \left[-c (M/M_0)^{-\alpha} \cdot t' \right] \quad (6.1)$$

From this description it follows then, that the double differential cross section may be parameterised in the form :

$$\frac{d^2\sigma}{dt' dM} = f(M) \cdot \exp \left[-c (M/M_0)^{-\alpha} \cdot t' \right] \quad (6.2)$$

where again the whole t' dependence is contained in the exponential function. In order to find the shape of the function $f(M)$ it is interesting to note, that the effective mass distribution is given by the integration of the double-differential distribution (6.2) over t' :

$$\frac{d\sigma}{dM} = \int dt' \frac{d^2\sigma}{dt' dM} = \int dt' f(M) \cdot \exp \left[-c (M/M_0)^{-\alpha} \cdot t' \right] \quad (6.3)$$

On the other hand in section 4.3 it was shown that the formula (4.3)

$$\frac{d\sigma}{dM} = \sigma_0 e^{kM} \quad (6.4)$$

describes well the experimental data (both the distributions of M for all events and for events with $t' \leq 1.0 \text{ (GeV/c)}^2$). In principle the integration in the formula (6.3) should be extended from $t' = 0$ to $t' = t'_{\max}$. In practice, however, $t'_{\max}$ is a complicated function of the missing mass M and, therefore, it is easier to integrate formula (6.3) over the range of t' from 0 to 1.0 (GeV/c)^2 . One then gets

$$\frac{d\sigma}{dM} = f(M) \cdot \frac{1}{c} (M/M_0)^{\alpha} \cdot \left\{ 1 - \exp \left[-c (M/M_0)^{-\alpha} \right] \right\} = \sigma_0 e^{kM} \quad (6.5)$$

and

$$f(M) = \sigma_0 c (M/M_0)^{-\alpha} \cdot \frac{e^{kM}}{1 - \exp \left[-c (M/M_0)^{-\alpha} \right]} \quad (6.6)$$

Then the two-dimensional parameterisation is given by

$$\frac{d^2\sigma}{dt' dM} = \sigma_0 c (M/M_0)^{-\alpha} \cdot \frac{\exp \left[kM - c (M/M_0)^{-\alpha} \cdot t' \right]}{1 - \exp \left[c (M/M_0)^{-\alpha} \right]} \quad (6.7)$$

where $\alpha = 2.34 \pm 0.12$, $M_0 = 1.0 \text{ GeV}$, $c = 26.4 \pm 2.5 \text{ GeV}^{-2}$, and the parameters σ_0 and k are $44.3 \pm 2.1 \text{ } \mu\text{b/GeV}$ and $1.33 \pm 0.05 \text{ GeV}^{-1}$ respectively for K^+p experiment at 8.2 GeV/c and $34.1 \pm 1.7 \text{ } \mu\text{b/GeV}$ and $1.31 \pm 0.05 \text{ GeV}^{-1}$, respectively for K^-p experiment at 10.1 GeV/c .

The regions, in which the parameters given above were fitted to the data, are shown in the modified Chew-Low plots presented in fig. 6.1 as the rectangle delimited by the solid lines. The dashed lines represent the kinematic limits. As can be seen, although the

regions of strict validity of the parameterisation cover about 5% of the total kinematically allowed phase-space, the rectangles contain about 50% of the total number of events because of the strong concentration of the events in the region of small four-momentum transfer t' and large effective mass M . The comparison of the parameterisation predictions with the experimental data is shown in figs 6.2 - 6.6. The parameterisation curves are drawn as solid lines for the regions of strict validity of the parameterisation defined as the regions, in which more than 90% of events come from the rectangles in fig. 6.1. The extrapolations of the parameterisation to the other regions are presented as dotted lines. As can be seen, the solid lines cover a relatively small range of the distributions (see e.g. fig. 6.2) or even in case of $p_{\perp}^2$ distributions (fig. 6.4) there is no region of strict validity of parameterisation. However, the extrapolations of the parameterisation outside the regions of strict validity satisfactorily describe about 80% of the events.

The parameterisation is definitely inadequate in the regions of the reflection of resonance production, e.g. high laboratory momentum region in fig. 6.2 or high center-of-mass longitudinal momentum values in fig. 6.3. It fails also in the region corresponding to backward emission of kaons in the c.m. system. Those regions were not taken into account when performing the original fits to the data.

The problem of resonance production is a rather difficult one. However, backward emission of kaons might be probably taken into account in an attempt to parameterise data in terms of effective mass M and transverse momentum squared $p_{\perp}^2$.

FIGURE CAPTIONS

- 6.1 The modified Chew-Low plot of t' versus M for all K^0 events produced in K^+p and K^-p interactions. The solid lines delimit the regions in which formulae (4.3) and (4.4) have been fitted to the data. The dashed lines represent the kinematic limits.
- 2 The comparison of the parameterisation prediction with the data for K^0 laboratory momentum distributions. The solid lines represent the region of strict validity (see text), the dotted lines are for the extrapolation.
- 6.3. The comparison of the parameterisation prediction with the data for the normalised c.m. longitudinal momentum distributions of K^0 mesons. The solid lines represent the region of strict validity (see text), the dotted lines are for the extrapolation.
- 6.4. The comparison of the parameterisation prediction with the data for the transverse momentum squared distributions of K^0 mesons.
- 6.5 The comparison of the parameterisation prediction with the data for the distribution of the squared four-momentum transfer t from incident kaon to produced K^0 .
- 6.6 The comparison of the parameterisation prediction with the data for the $t' = |t - t_{\min}|$ distributions of K^0 mesons.

Fig. 6.1

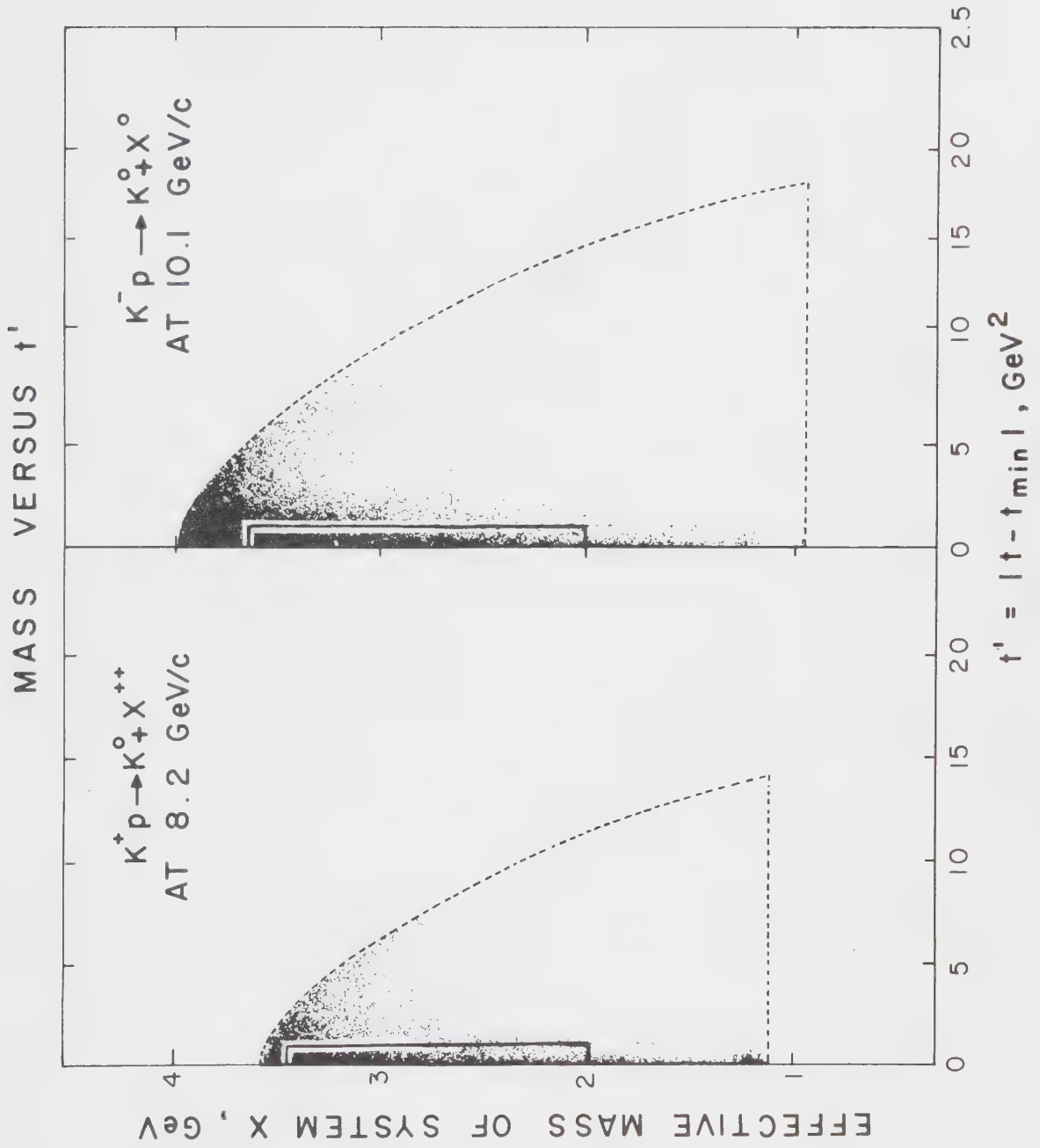


Fig. 6.2

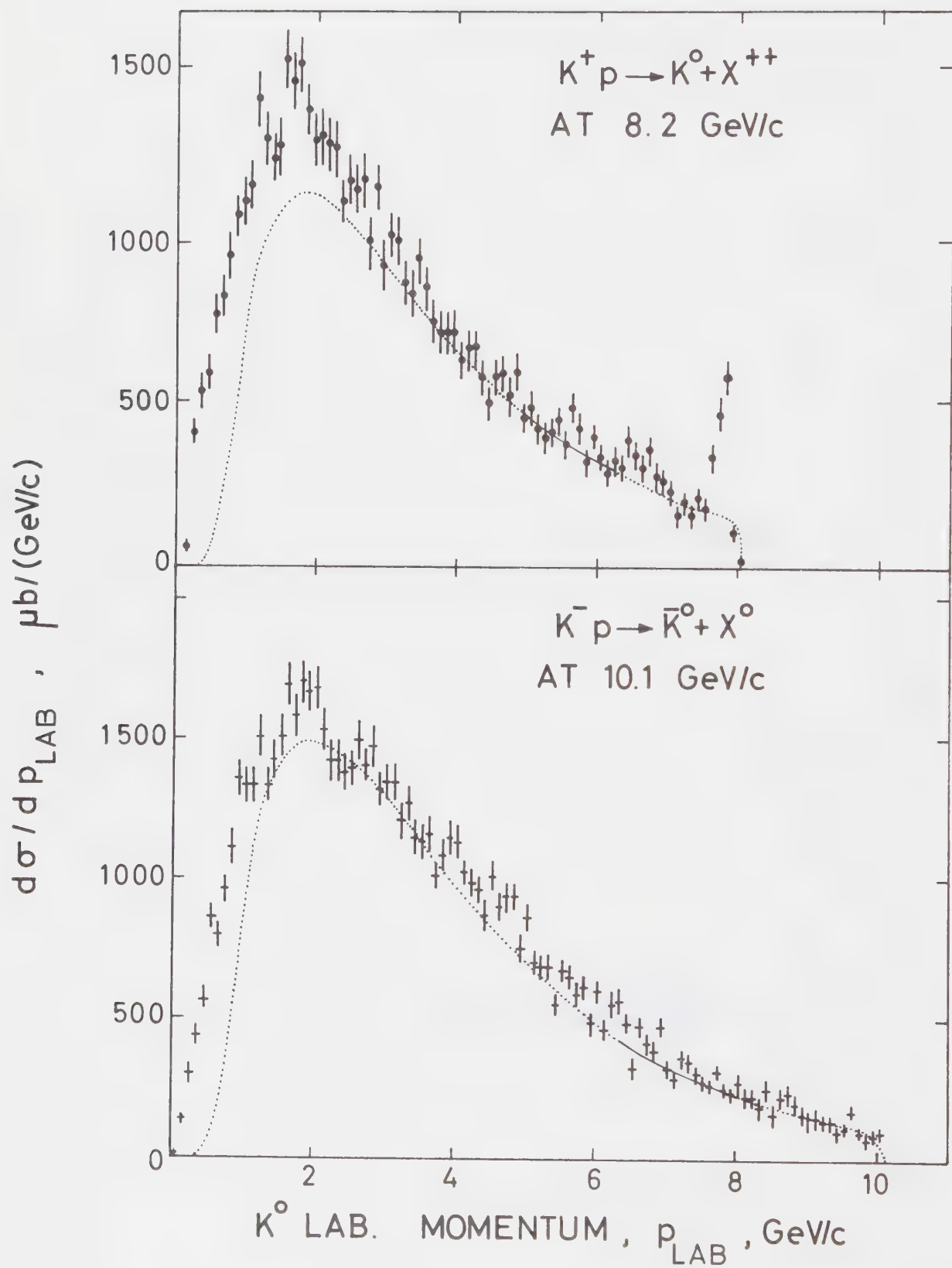


Fig. 6.3

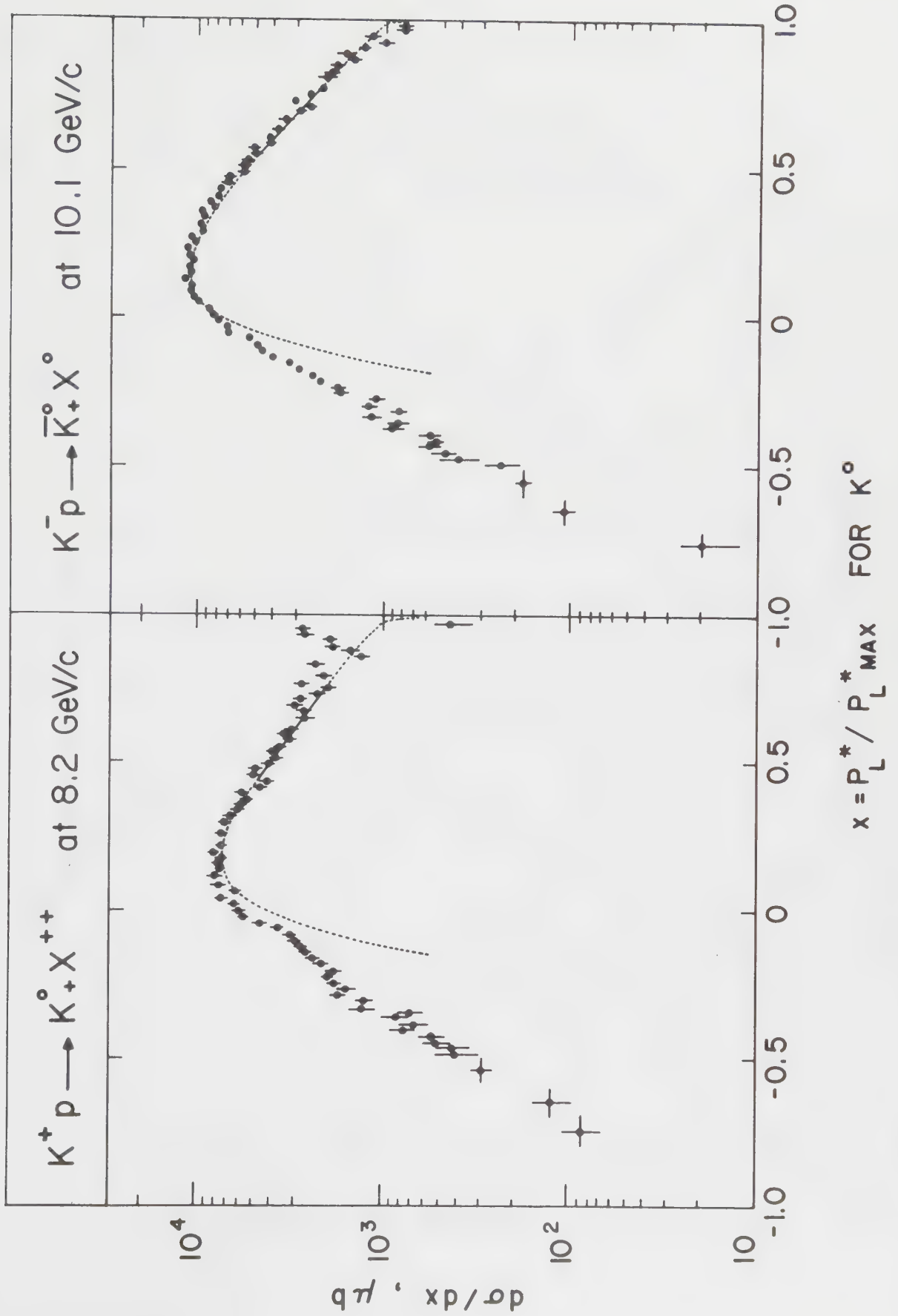


Fig. 6.4

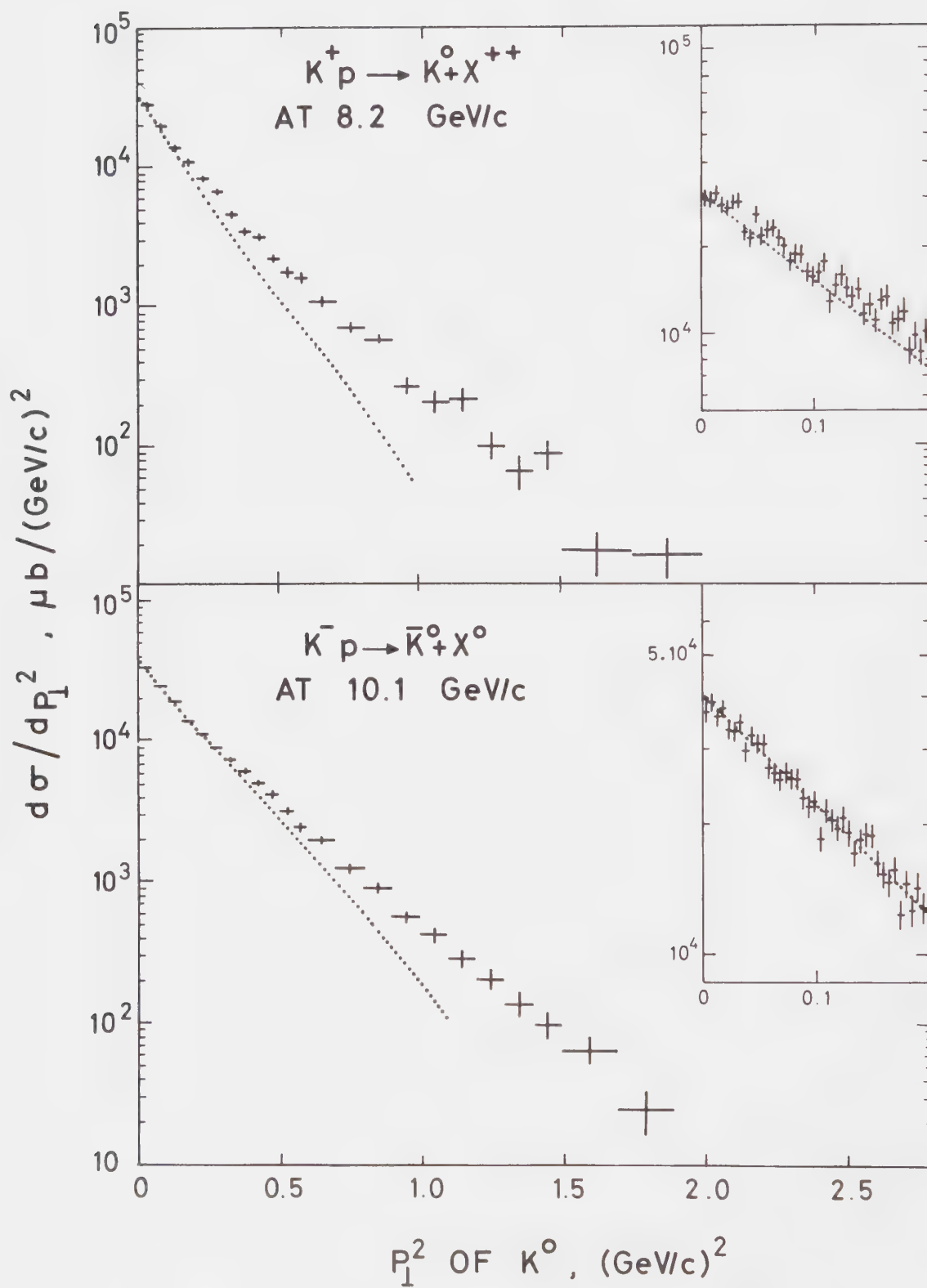


Fig. 6.5

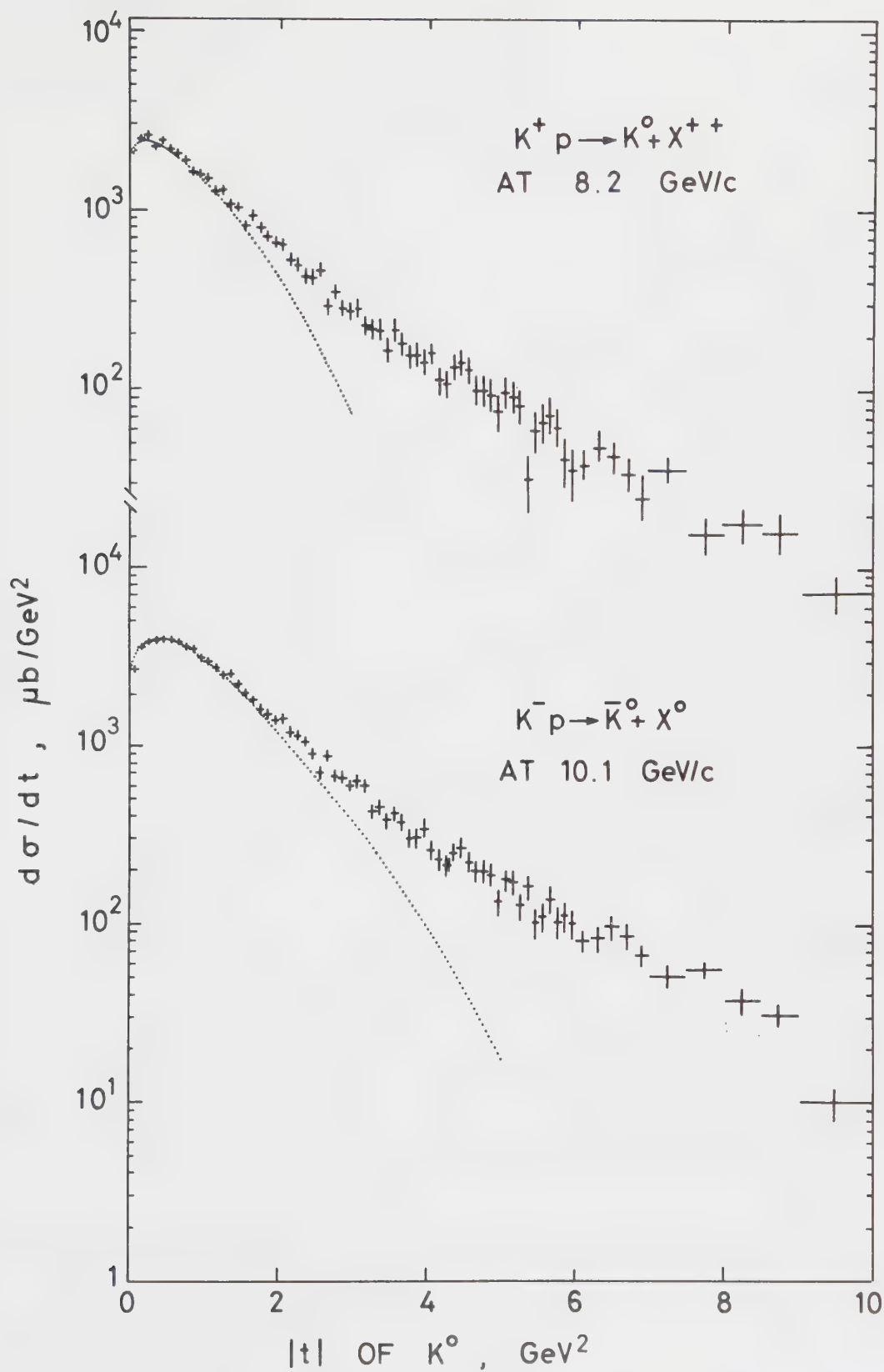
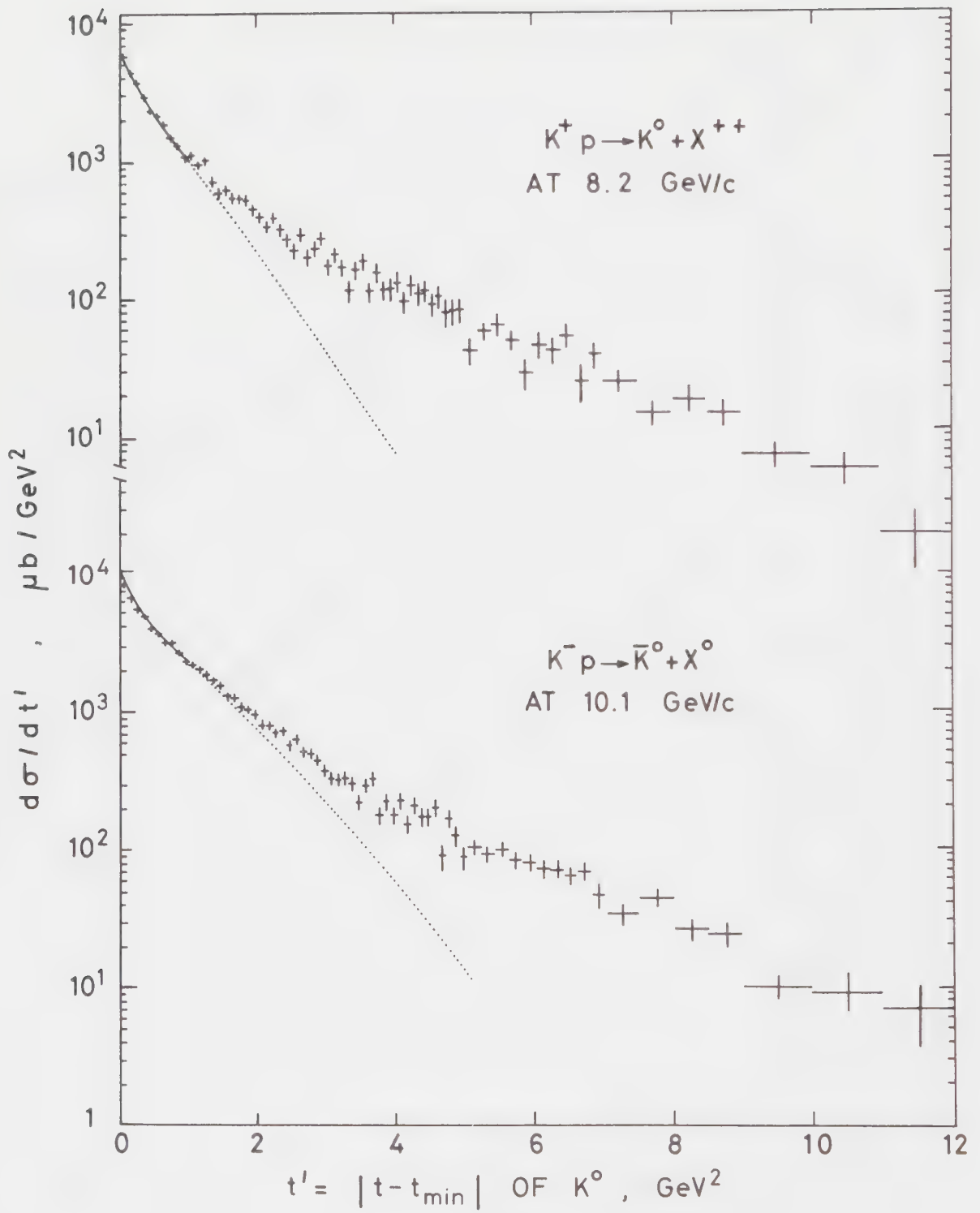
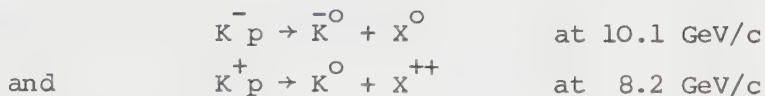


Fig. 6.6



7. CONCLUSIONS

In the work presented we have studied the charge-exchange inclusive reactions



The main experimental results obtained in the analysis of these reactions may be summarized as follows :

- a) The production characteristics of K^0 -mesons in $\bar{K}^- p$ and $K^+ p$ inclusive reactions shows no qualitative difference (apart from the value of the absolute cross sections and the reflections of different resonances) for $K^+ p$ and $\bar{K}^- p$ interactions.
- b) The distribution of the missing mass to the K^0 -meson is well described by an exponential function above the region of resonance production. The values of the exponential slopes are of the order of about 2 GeV^{-1} and decrease slowly with increasing incoming momentum.
- c) The $d\sigma/dt'$ distribution for a given band of missing mass can be fitted, for small t' values, with the exponential function $\exp(-At')$, where the slope A decreases with increasing mass approximately as about M^{-2} .
- d) For a fixed band of missing mass, a strong energy dependence of the cross section is observed ($\propto p_{\text{LAB}}^{-2.5}$), similar to the behaviour of the cross section for quasi two-body reactions.
- e) The distributions of the transverse momentum squared of K^0 -mesons may be in first approximation better described by an exponential function than by the Cocconi-Koester-Perkins formula.
- f) The average transverse momentum as a function of the longitudinal momentum of K^0 reveals the sea-gull effect, which cannot be fully explained as due to phase-space.

- g) The fraction of the total inelastic Kp cross section associated with K^0 production is approximately independent of incoming momentum in the range $3 < p_{\text{LAB}} < 10$ GeV/c, possibly indicating that the probability of charge exchange process for the incoming particle is constant with energy.
- h) The experimental cross sections for the different reaction channels with $K^0 (\bar{K}^0)$ in the final state do agree quite well with the theoretical values expected from the statistical Fermi model when isospin invariance is assumed.
- i) The total multiplicity distribution calculated from the measured cross sections under assumption of isospin invariance seems to be described much better by the Czyzewski-Rybicki formula than by the simple Poisson distribution.
- j) The dependence of the average charged multiplicity on the effective mass of the system X follows rather the power than the logarithmic law, at variance with the simple multiperipheral model suggesting (by analogy to the energy dependence of the average multiplicity) the logarithmic dependence.
- k) Except for the missing mass distributions, which seem to be well reproduced by phase-space alone, one needs to introduce some dynamical mechanism in order to describe the experimental data.
- l) About 80% of the data are well described by the fully-differential parameterisation in t' and M derived from the fits performed in relatively small ranges of single particle distributions.

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